Main Regularities and Health Risks from Exposure to Non-Thermal Microwaves of Mobile Communication

Igor Belyaev

Abstract — **Various responses to non-thermal microwaves (MW) from mobile communication including adverse health effects related to electrohypersensitivity, cancer risks, neurological effects, and reproductive impacts have been reported while some studies reported no such effects. This presentation provides an overview of the complex dependence of the MW effects on various physical and biological variables, which account for, at least partially, an apparent inconsistence in the published data. Among other variables, dependencies on carrier frequency, polarization, modulation, intermittence, electromagnetic stray fields, genotype, physiological traits, and cell density during exposure were reported. Nowadays, biological and health effects of 5G communication, which will use microwaves of extremely high frequencies (millimeter waves MMW, wavelength 1- 10 mm), are of significant public concern. It follows from available studies that MMW, under specific conditions of exposure at very low intensities below the ICNIRP guidelines, can affect biological systems and human health. Both positive and negative effects were observed in dependence on exposure parameters. In particular, MMW inhibited repair of DNA damage induced by ionizing radiation at specific frequencies and polarizations. To what extend the 5G technology and the Internet of Things will affect the biota and human health is definitely not known. However, based on possible fundamental role of MMW in regulation of homeostasis and almost complete absence of MMW in atmosphere due to effective absorption, which suggests the lack of adaptation to this type of radiation, the health effects of chronic MMW exposures may be more significant than for any other frequency range.**

Keywords — **Thermal and non-thermal effects of microwaves, Millimeter waves, 5G mobile communication, Health risks, Cancer, Physical mechanisms.**

I. Thermal versus Non-Thermal Microwave Effects, Their Main Regularities

Exposures to microwaves (MW, 300 MHz-300 GHz) vary in many parameters: incident power density (PD), specific absorption rate (SAR), frequency/wavelength, polarization (linear, ellipsoidal, circular, unpolarized), continuous wave (CW) and pulsed fields, modulation (amplitude, frequency, phase, complex), far field/near field, static magnetic field (SMF) and stray electromagnetic fields (EMF) of extremely low frequency (ELF, 3-300 Hz) at the location of exposure, overall duration and intermittence of exposure (interrupted, continuous), short-term acute and prolonged chronic exposures. With increased SAR, so-called thermal effects of MW are usually observed that result in significant MW-induced heating. SAR is a main determinate of thermal MW effects. The SAR based safety limits, which intend to protect from the thermal MW effects, were developed based on computer simulation of the MW energy absorption in standardized male phantoms. Thus, they do not take into account individual variability in voxel SAR distribution, which may be observed in dependence on polarization, frequency, age, sex, and pregnancy status [1-8]. In addition, the mobile phone SAR values are usually obtained when the phone is positioned about 2 cm from the standard male phantom head, a condition, which is not usually maintained during mobile phone calls. Other aforementioned physical variables of MW exposure have been linked to occurrence of so-called non-thermal (NT) biological effects, which are induced by MW at intensities well below measurable heating [9-21] [22]. The classification of MW effects into thermal and non-thermal is not based on physics of interaction between MW and biological tissues but rather reflects experimental observation of heating induced by MW exposure, which at SAR levels higher than 2 W/kg may result in thermal injury. Of note, slight temperature increase is also observed in the head tissues during exposure to mobile handset radiation, but this increase is too weak to produce thermal injury [23] and even to be sensed by the exposed subjects [24] while some mobile phone users reported sensation of warmth around the ear [25].

Vilenskaya and co-authors [26] and Devyatkov [27] have reported pioneering data on the NT effects of millimeter waves (MMW, 30-300 GHz, wavelength 1-10 mm in vacuum, to be used in 5G mobile communication) upon exposure of various biological objects. Webb was the first to establish the highly resonant effects of ultra-weak MMW on the induction of λ-phage in lysogenic bacterial E. coli cells [28]. These findings were subsequently corroborated by independent research groups [29, 30]. In these and subsequent studies the observed spectra of MMW action were found to have the following regularities: (1) strong dependence on frequency (frequency windows of resonance type), (2) there was a specific PD threshold below which no effect was observed, and above which the effects of exposure depended only weakly on power over several orders of magnitude (so-called

Igor Belyaev is with the Cancer Research Institute, Biomedical Research Center, University Science Park for Biomedicine, Slovak Academy of Sciences, Dubravska cesta 9, 845 05 Bratislava, Slovak Republic (e-mail: Igor.Beliaev@savba.sk).

sigmoid or S-shaped dependence), (3) the occurrence of MMW effects depended on the duration of exposure, a certain minimum duration of exposure was necessary for an effect to manifest itself. These important regularities of NT MMW effects have previously been confirmed by independent laboratories and reviewed [9, 14-16, 22, 31-34].

Since that time, multiple studies performed by diverse research groups over the World have provided strong evidence for the NT MW effects and have also indicated that there are several consistent regularities in occurrence of these effects: (i) dependence on frequency of "resonance-type" within multiple, while relatively narrow frequency windows; (ii) narrowing of these frequency windows with decreasing intensity of exposure; (iii) dependence on modulation, pulse modulated MW being usually more effective as CW MW; (iv) dependence on polarization, right- or left-circular polarization being more defective then opposite circular and linear polarization specifically for each resonance; (v) power windows and sigmoid dependence on PD within specific intensity windows including super-low PD comparable to intensities from base stations; (vi) thresholds on duration of exposure (coherence time); (vii) dependence on post-exposure time, intermittence and duration of exposure resulting in interplay between accumulated effect and adaptation to exposure; (viii) dependence on cell density suggesting electromagnetic cell-to-cell interaction during exposure; (ix) dependence on several physiological conditions during exposure, such as concentration of divalent ions, oxygen and radical scavengers, stage of cell growth; (x) dependence on genotype. Cell type, sex, age, individual differences, and SMF and stray ELF EMF during exposure can be of importance for the NT MW effects [20, 35]. The data showing dependence of MW effects on extremely low frequency and static magnetic fields at the location of exposure suggested a strategy for reducing health effects from MW of mobile communication.

II. Reproducibility Issues

Eventual non-reproducibility of the NT MW effects in replication studies is a subject of continues debate. As a matter of fact, dependence of the NT MW effects on several biological variables and physical parameters represents an important issue for considering in replication studies. Contrary to some statements, no one from positive studies (reporting NT MW effects) has been dismissed in a valid replication. One of the first studies on MMW effects was published by Webb [36]. The regulation of gene expression for the induction of prophage λ in lysogenic Escherichia coli has been extensively studied at the molecular level. The chain of events leading to induction by DNA-damaging factors, and the involvement of the RecA bacterial protein are well known. Webb has demonstrated, however, that the switching of the prophage genes from lysogenic to lytic development can be accomplished by exposure to MMW at the resonance frequency of 70.4 GHz. We followed the requirements described by Webb [37] as essential for MMW induction of prophage λ and replicated his data [37].

Of note, no one negative study (showing no effects) has been independently replicated. The most representative so far international panel of 30 scientists has stated in the monograph of the International Agency for Research on Cancer (IARC) on carcinogenesis of radiofrequency (RF, 30 kHz - 300 GHz) radiations, pages 101-102: "The reproducibility of reported effects may be influenced by exposure characteristics (including SAR or power density, duration of exposure, carrier frequency, type of modulation, polarization, continuous versus intermittent exposures, pulsed-field variables, and background electromagnetic environment), biological parameters (including cell type, growth phase, cell density, sex, and age) and environmental conditions (including culture medium, aeration, and antioxidant levels)" [35]. The IARC international panel admitted also that some of the inconsistencies between RF studies could be due to differences in species, page 416 [35], and other biological factors, page 104: "Biological systems are complex and factors such as metabolic activity, growth phase, cell density, and antioxidant level might alter the potential effects of RF radiation". Multiple physical variables that may affect study results were considered in the IARC monograph on pages 385-387 [35].

III. Health Risks

Results of several studies of RF effects on sperm quality have recently been reviewed and subjected to meta-analysis using random effect models, in order to determine whether exposure to RF emitted from mobile phones affects human sperm [38]. The sperm quality was measured using parameters, which are most frequently used in clinical settings to assess fertility by motility, viability and concentration. Exposure to mobile phones was associated with reduced sperm motility and viability, while the effects on concentration were more equivocal. These results, being consistent through observational in vivo and experimental in vitro studies, suggested that exposure from mobile phones negatively affects sperm quality.

Most epidemiologic studies indicate detrimental effects of chronic exposure radiation from mobile phones including increased brain cancer risks in heavy mobile phone users, while lower quality studies underestimated this risk [39-42] [43]. The reported brain cancer risk was dependent on type of signal and mutual position of the affected organ and mobile phone.

The majority of studies with chronic exposure to EMF from mobile phones showed detrimental effects including those related to carcinogenicity and also indicated mechanism of these effects, which is based on induction of reactive oxygen species (ROS) [44, 45]. In particular, few recent meta-analyses of available case-control studies have consistently shown that long term mobile phone use (usually ≥ 10 years) is associated with statistically significant increased risks of brain tumors (gliomas and acoustic neuromas) while no such association is seen at shorter usage [39-42]. An increased incidence of glioma in the brain and malignant schwannoma in the heart has recently been found in rats in the National Toxicology Program (NTP) study [46]. Acoustic neuroma, also called vestibular schwannoma, is a similar type of tumor as the malignant schwannoma found in the heart, also benign. Thus, the NTP results, which were obtained upon chronic

MW exposure of laboratory animals, have supported epidemiological human studies, which have found increased risk for glioma and acoustic neuroma.

The NTP findings along with recent replicated animal studies from Germany [47], supplemented other studies and provided sufficient evidence for carcinogenicity of mobile phone exposure in animals. Studies with chronic exposures have also provided evidence for possible mechanisms of MW effects, which involve production of reactive oxygen/nitrogene species. Taking into account the evidence from human epidemiological studies, MW exposure from mobile phones was suggested to be classified as human carcinogen according to the generally accepted Bradford Hill criteria [35, 48]. The interadvisory group of 29 scientists from 18 countries of the International Agency for Research on Cancer (IARC), which is a part of the World Health Organization, has recently stated that the majority of NTP data on carcinogenic bioassay provided evidence for re-evaluating the RF-induced carcinogenesis [49].

Other potential health effects of MW exposure including nervous system diseases and hypersensitivity to electromagnetic fields have recently been reviewed [50, 51].

IV. Mobile Base Stations

Population's exposure to microwaves from base stations continuously grows. Recent studies with individual RF dosimeters indicated that the mobile phone base stations is a major source of whole body exposure to RF [52]. Very few studies are available on effects of MW-exposure from mobile base stations. Notably, most of them indicate adverse health effects, including cancer, fertility and prenatal development under chronic exposures of humans [1-9], mammals [10] and birds [11]. Accumulated dose during chronic exposure seems to be important parameter for assessment of cancer risks from base stations. In Taiwan, Li et al. performed a population-based case-control study and considered cancer incidence cases ≤15 years, which were admitted in 2003-2007 for all neoplasm including leukemia and brain tumors [53]. The cancer risks were estimated versus annual summarized power (ASP, W-year) accumulated during chronic exposures to each of the 71,185 base stations in service in 1998-2007. The annual power density (APD, W-year/km^2) was computed from all base stations. RF exposure of each study case was indicated by the averaged APD within 5 years prior to the neoplasm diagnosis. A was significantly associated with an increased cancer risks for all neoplasm. Thus, this study found a significantly increased risk of all neoplasm in children with higher than median averaged APD (about 168 W-year/km^2) exposure to base stations.

V. Physical Mechanisms

There is an emerging notion that physics of non-equilibrium and nonlinear systems should underlie the physical mechanisms of the NT MW effects [54-63]. According to theoretical analysis of available experimental data on the MW effects at super-weak PD these effects should be considered in frame of quantum-mechanical approach [56, 64]. A fundamental quantum-mechanical mechanism has been suggested by Fröhlich who postulated that biological systems exhibit coherent longitudinal vibrations of electrically polar structures such as biological membranes [57]. According to the Fröhlich's mechanism, when the metabolically driven energy supply exceeds a critical level, the polar structure enters a condition in which a steady state of non-linear oscillation is reached. The Fröhlich's mechanism has also predicted the existence of a resonant interaction of MMW with biosystems [65, 66]. Possible biophysical mechanisms for the NT MW effects have been reviewed elsewhere [67].

VI. 5G versus GSM/UMTS

We tested some signals from GSM (Global System for Mobile Communication, 2G) and UMTS (Universal Mobile Telecommunications System, 3G) mobile phones [68, 69]. Contrary to GSM phones, mobile phones of the 3rd generation irradiate wide-band signal. UMTS MWs may result in higher biological effects due to presence of selective resonance frequency windows.

Most current discussion regarding MW health effects is focused on the 5G mobile communication, which is promptly enrolled in different countries and uses frequency ranges similar to 2G/3G/4G plus MMW. It follows from available studies that MW, under specific conditions of exposure at ultra-weak intensities below the ICNIRP guidelines, can affect biological systems and human health. Both positive and negative effects were observed in dependence on exposure parameters. In particular, MMW inhibited repair of DNA damage induced by ionizing radiation at specific frequencies, modulations and polarizations [21].

While MMW are almost completely absorbed within 1-2 mm in biologically equivalent tissues, it may penetrate much deeper in live human body. Biological objects including human being are not in thermodynamical equilibrium. Thus, except for considering penetration of 5G/MMW into biologically equivalent tissues being in thermodynamical equilibrium, the response of live human body should also be considered. Alive body represents a complicated system with fundamental frequencies; many of them lie in the MMW range. In particular, the acupuncture system (meridians of organs) has been considered as a waveguide system for these MMW fundamental modes in the Soviet/Russian literature. From this point of view, MW penetrates human body far deeply as compared to "dead" model phantoms. Electromagnetic origin of Chinese meridians has been studied in several Soviet research teams. For example, Sit'ko et al. described the frequency of 56.46 GHz, which was found during an ordinary search for therapeutic frequencies based on sensorial reactions of a patient with duodenal ulcer [70]. Negative sensation (defined as spastic contraction of musculus quadricepts femoris) was repeatedly observed under applying MMW at this frequency. This sensory reaction allowed tracking the Chinese stomach meridian by using a static magnet at 4 mT. Exposure at the frequency of 56.46 GHz has worsened health condition of the patient. Thus, this exposure was aborted and the patient received treatment at the resonance therapeutic frequency found by typical positive sensations. After successful healing the duodenal ulcer at the MMW resonance therapeutic frequency, the negative response of the patient to the frequency of 56.46 GHz disappeared.

When a very fast RF pulse enters a human body, it generates a burst of energy (a Brillouin precursor) that can travel much deeper than predicted by the conventional models [71]. Brillouin precursors can be formed by high-speed data signals as used in 5G.

VII. Conclusions

To what extend the 5G technology and the Internet of Things will affect the human health is definitely not known. However, based on possible fundamental role of MMW in regulation of homeostasis [72] and almost complete absence of MMW in atmosphere due to effective absorption, which suggests the lack of adaptation to this type of radiation, the health effects of chronic MMW exposures may be more significant than for any other frequency range. From the health perspectives, implementation of the 5G technology is premature. Extended research with chronic exposure of human cells, animals and man is needed to exclude potentially harmful 5G signals.

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Planetary electromagnetic pollution: it is time to assess its impact

As the Planetary Health Alliance moves forward after a productive second annual meeting, a discussion on the rapid global proliferation of artificial electromagnetic fields would now be apt. The most notable is the blanket of radiofrequency electromagnetic radiation, largely microwave radiation generated for wireless communication and surveillance technologies, as mounting scientific evidence suggests that prolonged exposure to radiofrequency electromagnetic radiation has serious biological and health effects. However, public exposure regulations in most countries continue to be based on the guidelines of the International Commission on Non-Ionizing Radiation Protection[1] and Institute of Electrical and Electronics Engineers,[2] which were established in the 1990s on the belief that only acute thermal effects are hazardous. Prevention of tissue heating by radiofrequency electromagnetic radiation is now proven to be ineffective in preventing biochemical and physiological interference. For example, acute non-thermal exposure has been shown to alter human brain metabolism by NIH scientists,[3] electrical activity in the brain,[4] and systemic immune responses.[5] Chronic exposure has been associated with increased oxidative stress and DNA damage[6,7] and cancer risk.[8] Laboratory studies, including large rodent studies by the US National Toxicology Program[9] and Ramazzini Institute of Italy,[10] confirm these biological and health effects in vivo. As we address the threats to human health from the changing environmental conditions due to human activity,[11] the increasing exposure to artificial electromagnetic radiation needs to be included in this discussion.

Due to the exponential increase in the use of wireless personal communication devices (eg, mobile or cordless phones and WiFi or Bluetooth-enabled devices) and the infrastructure facilitating them, levels of exposure to radiofrequency electromagnetic radiation around the 1 GHz frequency band, which is mostly used for modern wireless communications, have increased from extremely low natural levels by about 10^{18} times (figure). Radiofrequency electromagnetic radiation is also used for radar, security scanners, smart meters, and medical equipment (MRI, diathermy, and radiofrequency ablation). It is plausibly the most rapidly increasing anthropogenic environmental exposure since the mid-20th century, and levels will surge considerably again, as technologies like the Internet of Things and 5G add millions more radiofrequency transmitters around us.

Unprecedented human exposure to radiofrequency electromagnetic radiation from conception until death has been occurring in the past two decades. Evidence of its effects on the CNS, including altered neurodevelopment[14] and increased risk of some neurodegenerative diseases,[15] is a major concern considering the steady increase in their incidence. Evidence exists for an association between neurodevelopmental or

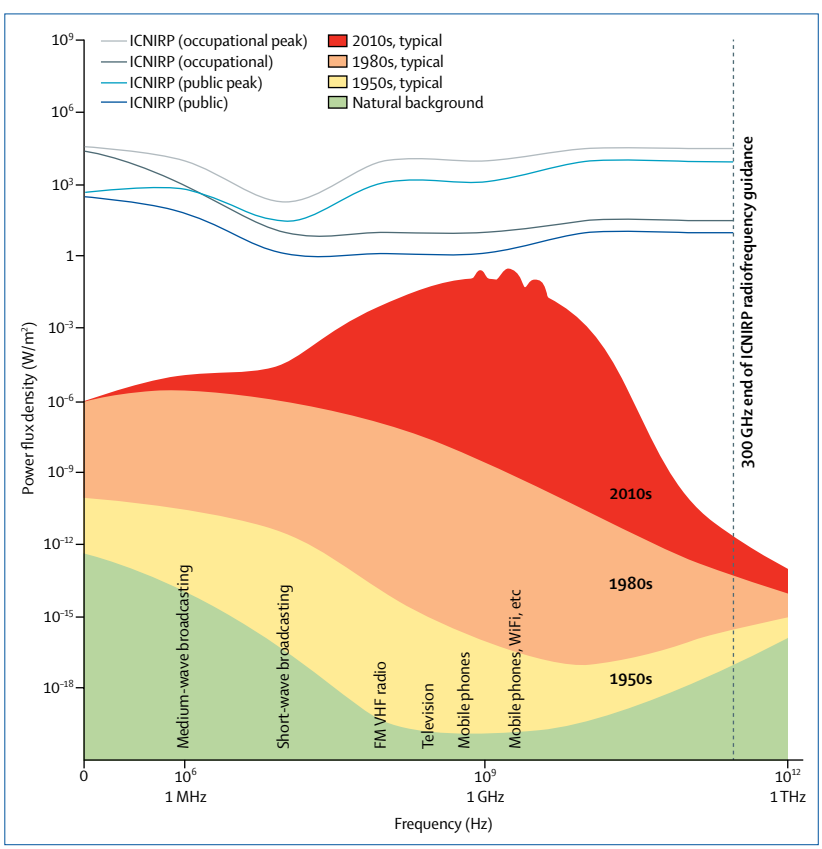

Figure: **Typical maximum daily exposure to radiofrequency electromagnetic radiation from man-made and natural power flux densities in comparison with International Commission on Non-Ionizing Radiation Protection safety guidelines[1]**

Anthropogenic radiofrequency electromagnetic radiation levels are illustrated for different periods in the evolution of wireless communication technologies. These exposure levels are frequently experienced daily by people using various wireless devices. The levels are instantaneous and not time-averaged over 6 minutes as specified by International Commission on Non-Ionizing Radiation Protection for thermal reasons. Figure modified from Philips and Lamburn[12] with permission. Natural levels of radiofrequency electromagnetic radiation were based on the NASA review report CR-166661.[13]

behavioural disorders in children and exposure to wireless devices,[14] and experimental evidence, such as the Yale finding, shows that prenatal exposure could cause structural and functional changes in the brain associated with ADHD-like behaviour.[16] These findings deserve urgent attention.

For the **Oceania Radiofrequency Scientific Advisory Association** see www.orsaa.org

At the Oceania Radiofrequency Scientific Advisory Association, an independent scientific organisation, volunteering scientists have constructed the world's largest categorised online database of peer-reviewed studies on radiofrequency electromagnetic radiation and other man-made electromagnetic fields of lower frequencies. A recent evaluation of 2266 studies (including in-vitro and in-vivo studies in human, animal, and plant experimental systems and population studies) found that most studies (n=1546, 68·2%) have demonstrated significant biological or health effects associated with exposure to anthropogenic electromagnetic fields. We have published our preliminary data on radiofrequency electromagnetic radiation, which shows that 89% (216 of 242) of experimental studies that investigated oxidative stress endpoints showed significant effects.[7] This weight of scientific evidence refutes the prominent claim that the deployment of wireless technologies poses no health risks at the currently permitted non-thermal radiofrequency exposure levels. Instead, the evidence supports the International EMF Scientist Appeal by 244 scientists from 41 countries who have published on the subject in peer-reviewed literature and collectively petitioned the WHO and the UN for immediate measures to reduce public exposure to artificial electromagnetic fields and radiation.

For the **International EMF Scientist Appeal** see www.emfscientist.org

Evidence also exists of the effects of radiofrequency electromagnetic radiation on flora and fauna. For example, the reported global reduction in bees and other insects is plausibly linked to the increased radiofrequency electromagnetic radiation in the environment.[17] Honeybees are among the species that use magnetoreception, which is sensitive to anthropogenic electromagnetic fields, for navigation.

Man-made electromagnetic fields range from extremely low frequency (associated with electricity supplies and electrical appliances) to low, medium, high, and extremely high frequency (mostly associated with wireless communication). The potential effects of these anthropogenic electromagnetic fields on natural electromagnetic fields, such as the Schumann Resonance that controls the weather and climate, have not been properly studied. Similarly, we do not adequately understand the effects of anthropogenic radiofrequency electromagnetic radiation on other natural and man-made atmospheric components or the ionosphere. It has been widely claimed that radiofrequency electromagnetic radiation, being non-ionising radiation, does not possess enough photon energy to cause DNA damage. This has now been proven wrong experimentally.[18,19] Radiofrequency electromagnetic radiation causes DNA damage apparently through oxidative stress,[7] similar to near-UV radiation, which was also long thought to be harmless.

At a time when environmental health scientists tackle serious global issues such as climate change and chemical toxicants in public health, there is an urgent need to address so-called electrosmog. A genuine evidence-based approach to the risk assessment and regulation of anthropogenic electromagnetic fields will help the health of us all, as well as that of our planetary home. Some government health authorities have recently taken steps to reduce public exposure to radiofrequency electromagnetic radiation by regulating use of wireless devices by children and recommending preferential use of wired communication devices in general, but this ought to be a coordinated international effort.

Priyanka Bandara, David O Carpenter
Oceania Radiofrequency Scientific Advisory Association, Scarborough, QLD 4020, Australia (PB); and Institute for Health and the Environment, University at Albany, Rensselaer, NY, USA (DOC)
pri.bandara@orsaa.org

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Health effects of electromagnetic fields on children

Running title: Electromagnetic fields and children

Jin-Hwa Moon, MD, PhD

Department of Pediatrics, Hanyang University School of Medicine, Seoul, Republic of Korea

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Corresponding author

Jin-Hwa Moon, MD., PhD.

Department of Pediatrics, Pediatric Neurology, Hanyang University Guri Hospital, Gyeongchun-ro 153, Guri-si, Gyeonggi-do, 11923, Republic of Korea

Tel.: +82-31-560-2258, Fax: +82-31-552-9493, E-mail: jinhwamoon@hanyang.ac.kr

https://orcid.org/0000-0003-0235-5318

Abstract

In today's world, most children are exposed to various manmade electromagnetic fields (EMFs). EMFs are electromagnetic waves less than 300 GHz. A developing child's brain is vulnerable to electromagnetic radiation; thus, their caregivers' concerns about the health effects of EMFs are increasing. EMF exposure is divided into two categories: extremely low frequencies (ELFs; 3–3,000 Hz), involving high-voltage transmission lines and in-house wiring; and radio frequencies (RFs; 30 kHz to 300 GHz), involving mobile phones, smart devices, base stations, WiFi, and 5G technologies. The biological effects of EMFs on humans include stimulation, thermal, and nonthermal, the latter of which is the least known. Among the various health issues related to EMFs, the most important issue is human carcinogenicity. According to the International Agency for Research on Cancer's (IARC's) evaluation of carcinogenic risks to humans, ELFs and RFs were evaluated as possible human carcinogens (*Group 2B*). However, the World Health Organization's (WHO's) view of EMFs remains undetermined. This article reviews the current knowledge of EMF exposure on humans, specifically children. EMF exposure sources, biological effects, current WHO and IARC opinions on carcinogenicity, and effects of EMF exposures on children will be discussed. As well-controlled EMF experiments in children are nearly impossible, scientific knowledge should be interpreted objectively. Precautionary approaches are recommended for children until the potential health effects of EMF are confirmed.

Keywords: electromagnetic fields, extremely low frequencies, radio frequencies, smart device, children

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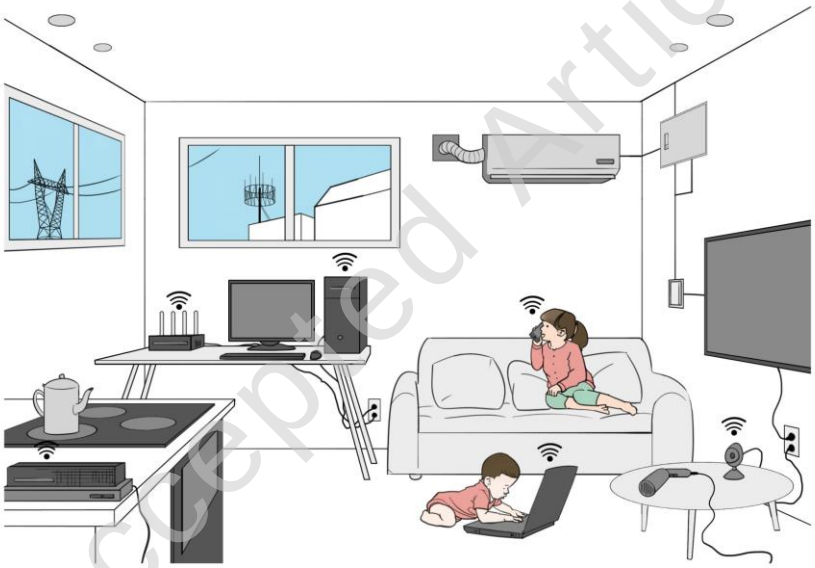
Key message

- The nervous systems of children are more vulnerable to the effects of electromagnetic waves than adults.
- The exposure to EMFs among children should be minimized.
- According to IARC EMFs are possibly carcinogenic, it should not be overlooked or interpreted with bias.

Graphical abstract



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The nervous systems of children are more vulnerable to the effects of electromagnetic fields (EMFs) than adults. Studies on the effects of EMFs on children's health are unestablished. However, precautionary principles should be followed for children, and the exposure to EMFs among children should be minimized.

Introduction

Electromagnetic radiation is generated from natural environments such as the solar energy and geomagnetic field or from manmade sources. With scientific and technological advancements, our everyday environments are filled with various manmade electromagnetic fields (EMFs). EMFs are invisible and generated from electrical lines, transmission towers, telecommunications, home appliances, mobile phones, WiFi, and base stations. An increasing number of children use computers and iPads for school, entertainment, and social activities. Even infants can be exposed to EMFs in the residential environment or by the direct use of electronic devices (Fig. 1).

There are two main categories of EMFs: extremely low frequency (ELF) and radiofrequency (RF) waves.[1-3] ELFs can be generated from electrical lines or transmission towers, issues of which have been investigated for the last several decades. RFs can be generated from mobile phones and smart devices and the recent 5th-generation (5G) technologies. The human effects of RFs are less evident and more difficult to study than those of ELFs.

In Korea, general measures have been recommended to reduce EMF exposure such as reducing the use of electronic devices or using them away from the body. However, little is known about the exact amount of daily EMF exposure that can affect a child's health and whether the effects of EMF exposure are similar to those of adults. The developing nervous system is more conductive and absorbs more electromagnetic energies than those of adults.[4] Therefore, different standards are required to protect children.

In recent years, pediatricians have become increasingly asked about children's use of electromagnetic devices and the risks of EMF exposure. Thus, more knowledge about pediatric exposure to electromagnetic radiation is required than any other time before. Thus,

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this article reviews the current knowledge about the health effects of EMF exposure on children. The World Health Organization's (WHO's) opinions and other scientific researches will be critically reviewed, and the precautionary principle to reduce the negative effects of EMF on children will be emphasized.

Sources of EMF exposure

Whenever electrical current flows, both electrical and magnetic fields are generated, known as EMFs. Electric field strength is measured as volts per meter (V/m), while magnetic field strength is measured as amperes per meter (A/m). A magnetic field can be measured as magnetic flux density (Tesla).

The electromagnetic spectrum is categorized into a frequency range: ELF, RF, infrared, visible, ultraviolet, and ionizing radiations (x- and γ-radiation).[1,3] EMF refers to waves less than 300 GHz, which includes most of the frequencies in everyday exposure. The lowest frequencies (3–3,000 Hz) are referred to as ELF-EMF, while the higher frequencies (30 kHz to 300 GHz, under infrared) are referred to as RF-EMF (Fig. 2).

Extremely low frequency EMFs

Extremely low frequency EMFs (ELF-EMFs) are generated from electricity, electrical machines, transmission towers, and high-voltage lines. In Korea, electric power is operated at 60 Hz. More EMFs are absorbed with the use of appliances that are close to the body (e.g., hair dryers, bidets, massagers, and electric blankets). The general recommendation is that electrical appliances should be used at least 30 cm away from the body (http://www.emf.or.kr/general/html/life/guideline.pdf).

Radio frequency EMFs

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Radio frequency EMFs (RF-EMFs) are generated from mobile phones, smart devices, WiFi, base stations, and radars. Radio or television transmitters and base stations can be large sources of RF exposure. Mobile phones generate more electromagnetic waves when used in a fast-moving subway or train or when searching for a base station before the ring back tone.[5)]

Biological effects of EMFs

The main effects of EMFs on the human body are stimulation, thermal, and nonthermal. Stimulation effects involve the nerves and muscles at a high EMF, can be used for medical devices, and can cause electrical shock at very high stimulation levels. Thermal effects involve an increase in body temperature. Hot senses of the ear or body during mobile phone or laptop use are some examples. Nonthermal effects result from recurrent long-term exposure and may be related to the so-called electromagnetic hypersensitivity syndrome or neurodevelopmental disorders. However, the nonthermal effect is the least well investigated.[6)]

The effects of EMF exposure differ with respect to frequencies and strength. For frequencies less than 300 GHz, limitation levels for human protection have been well established for public and occupational workers.[7,8)] From 100 KHz to 10 GHz, which includes the use of mobile phones, limitation level is expressed as a specific absorption rate (SAR, W/kg).[2,8)]

One of the major issues of EMF involves human carcinogenesis. Since the first report on residential ELF-EMF and childhood leukemia in 1979, several studies have investigated this association.[1,2,7)] However, because of the nature of electromagnetic radiation, most studies were based on epidemiological data or animal experiments.

Animal studies on prenatal RF exposure demonstrated the deleterious effects of RF-EMF on the brain. Prenatal exposure to 900 MHz resulted in substantial loss of granule cells[9)] or a

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significant reduction in pyramidal neurons.[10)] Mice exposed to in utero RF from cellular telephones were hyperactive and demonstrated memory impairment after birth.[11)] EMFs from mobile phones changed the blood-brain barrier's permeability and damaged neurons in the brains of exposed rats.[12-14)]

Brain oxidative stress and epigenetics are considered biological mechanisms of RF-EMF effects. Several theories suggest that EMF exposure results in oxidative stress and reactive oxygen species and loss of cells and blocks their production.[15)] Oxidative stress parameters increase lipid hydroperoxide and myeloperoxidase activity in immature rats.[16)] RF-EMF exposure may change deoxyribonucleic acid methylation, histone modification, chromatin remodeling, and microribonucleic acid.[16-18)] However, the results of studies on brain oxidative stress induced by EMF are inconsistent.

In Korea, many websites for public and nonpublic institutions provide information aiming to improve public awareness and EMF knowledge.[19-22)] This information includes objective data on human limitation levels, EMF measurements of electronic products, base station information, general safety guidelines, and false beliefs. Although the websites provide general information for public awareness, they sometimes conclude that the public concerns regarding carcinogenicity and nonthermal effects are exaggerated and have insufficient evidence. However, such conclusions may be hasty. Because evidence of the relevant websites is often based on WHO fact sheets, it is necessary for clinicians to review the WHO opinion and evaluate other scientific evidence objectively.

On the other hand, some individual websites or personal blogs deliver scientifically unreasonable negative information to users. Such messages exaggerate claims and interfere with reasonable discussions about EMF health effects.

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Different tones for human carcinogenicity

Carcinogenicity of ELF-EMF

In 1996, the WHO organized an international EMF project task group to investigate the potential health risks of EMF-associated technologies. In the resulting fact sheet in 2007, the WHO concluded that there were no substantive health issues related to ELF electric fields at levels generally encountered by the public.[7)] This position was based on findings and reviews of the WHO task group as well as the International Agency for Research on Cancer (IARC, 2002) and International Commission on Non-Ionizing Radiation Protection (2003).[2,7,23)] The WHO task group referenced the IARC monograph evaluating the carcinogenic risks in humans in 2002 that classified ELF as a possible carcinogen.[2)] However, the task group commented that the epidemiological evidence of carcinogenicity was weakened by methodological problems such as potential selection bias.[7)]

In fact, the IARC's 2002 monograph evaluated a number of scientific studies on ELF electronic and magnetic fields and childhood and adult cancers.[2)] In the part about the effects on children, it stated that "pooled analyses showed twofold excess risk for exposure to ELF magnetic fields above 0.4 μT and a relative risk of 1.7 for exposure above 0.3 μT.".[2)] The IARC concluded that ELF magnetic fields were possibly carcinogenic to humans *(Group 2B)* and that the association between child leukemia and a high magnetic field was unlikely to be due to chance.[2)] In contrast to ELF magnetic fields, evidence on the association between ELF electric fields and leukemia was inadequate, and the associations between other childhood brain tumors or cancers and ELF were inconsistent.[2)]

The IARC is a working group under the auspices of WHO. Despite this, the different views between the WHO and the IARC may have originated from the differences in their respective members. Many committee members of the WHO's EMF project were involved with

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electricity-associated industries, whereas the IARC membership included more epidemiologists and health specialists.[24] In Korea, several public websites on EMF safety frequently cite the WHO EMF opinion. Some citations seem to have been changed through self-citation, which may cause the misleading interpretation that there is no scientific evidence of carcinogenicity.

Carcinogenicity of RF-EMF

A large international case-control study (INTERPHONE study, 2000) that aimed to determine the association between adult brain tumor risk and mobile telephone use reported no overall increase in brain tumor risk with the use of mobile phones.[25] However, in the 10th highest decile of cumulative call time (≥1,640 h), the odd ratios were 1.4 for glioma and 1.15 for meningioma.[25] Glioma tended to occur more commonly in the temporal lobe on the side of usual phone use.[25] After the INTERPHONE study, in 2013, the IARC published another monograph evaluating the carcinogenic risks of RF-EMF on humans.[3] Similar to ELF magnetic fields, the IARC classified RF-EMFs as "possibly carcinogenic to humans *(Group 2B)*."[3]

In 2014, the WHO also published the following fact sheet on mobile phone EMF and public health.[26] Similar to ELF, the WHO opinion was undetermined; rather, it referenced the IARC's classification of mobile phone use as possibly carcinogenic to humans. However, the WHO group repeated the comment that the "biases and errors limit the strength of these conclusions and prevent a causal interpretation."[26] Such undetermined views of the WHO on the adverse effects of RF or ELF-EMF have been criticized by several scientist groups, which have requested that the WHO should reevaluate all health effects of EMF and include experts from all related fields such as health, medicine, and engineering to reassess the effects of EMFs.[24,27,28]

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Other EMF effects on children's health

In everyday life, children are exposed to indoor and outdoor EMFs. Although well-designed case-control studies are lacking, we can consider the available data in hypothesizing about the effects of EMF on children.

ELF effects on and children

ELF from high-voltage power lines can affect children living near them; in fact, children can be continuously affected by low-level in-house wiring. Much of the results regarding ELF and children's health are based on epidemiologic studies with childhood leukemia as described in the previous section.

While conducting the international EMF project, the WHO conducted an international workshop on "Sensitivity of children to EMF exposure" (Istanbul, Turkey, June 2004) of both ELF and RF-EMF exposure. They concluded that there was no direct evidence that children were more vulnerable to EMF because very few studies assessed this topic.[29)] However, considering the uncertain effects of EMF on children, the WHO recommended general measures such as reducing personal EMF exposure. They also recommended minimizing EMF exposure in schools, kindergartens, and any locations where children remain for a substantial part of the day.[1,29)]

RF effects on children

Whether children are vulnerable to RF has been debated for the last 20 years, when children were widely exposed to mobile phones. Human and animal model studies yielded significant findings regarding cellular phone use: increased headache, sleep disruption, neurotransmitter release, synaptic plasticity alterations, and neuronal cell cycles.[30-34)] However, the experimental environment and RF doses may differ from those of actual exposures.

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The Korean study conducted in 1993–1999 involving 1,928 children with leukemia and 956 children with brain tumors. It revealed that the risk of leukemia was 2.15 times higher in the group living within 2 km from AM radio transmitters than in the group living more than 20 km from it.[35)]

In 2000, the "Stewart report" by the UK Independent Expert Group on Mobile Phones declared that children may be more vulnerable to EMF than any other age groups.[4,36)] They stated that "*children are exposed to electromagnetic waves over a longer life time than adults and their nervous systems are in the process of development. As the conductivity of the children is higher due to higher moisture and ionic content than adults, and more than adults, children's head absorbs a lot of RF energy*" (Fig 3).[4)] Stewart's report suggested that children should not be encouraged to use mobile phones unnecessarily and that mobile phone companies should not promote their use in children.[4)] Since Stewart's report, debate regarding the vulnerability of a child's brain surfaced from the Netherlands and Russia.[37) 38)]

Studies of mobile phone RF exposure in children

The skull thickness of adults is approximately 2 mm. However, the skull thickness of a 5-year-old child is approximately 0.5 mm and 1 mm in 10 years.[39)] Therefore, radiation penetration is larger in children than in adults.[39,40)] As a child's head diameter is smaller, the energy-absorbing "hot spots," the most sensitive parts of RF, are more pronounced.[41)] Several engineering strategies to avoid the hazard of RF do not consider a child's head specificity.[6)]

The results of the study that assessed the associations between RF exposure and cell phone use, residential RF-EMF levels, and cognitive function tests were inconsistent.[42-46)] Ten-year-old children living in areas with higher RF exposure did not show any effects in most of the cognitive parameters; however, they did show lower verbal scores and higher internalizing and total problems.[46)] In a study of children aged 5–6 years, greater residential RF exposure

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from base stations and the presence of indoor sources were associated with improved inhibitory control and flexibility of cognition but also reduced visuomotor coordination.[47)]

The associations between RF exposure and mobile phone use and sleep in children are inconsistent.[48-50)] Habitual and frequent use of mobile phones was associated with lower sleep quality, while higher tablet use was associated with decreased sleep efficiency.[49)] Arousal and blue light may underlie these problems. Residential exposure to RF-EMF from base stations was not associated with sleep onset delay, night awakening, parasomnia, and daytime sleepiness in 7-year-old children; however, higher mobile phone use was associated with less favorable sleep duration, night awakening, and parasomnia.[50)]

Cell phone use by pregnant mothers during the pre- and postnatal periods can contribute to behavioral problems in children.[51)] In children exposed to cell phones during the pre- and postnatal periods, the odds ratio for behavioral problems was 1.8 after the adjustment of potential confounders.[52)]

Recently, the European Union–funded international study evaluating the association between RF exposure by mobile phones and brain tumor risk in children and adolescents (MOBI-KIDS) was conducted.[53)] This large study included nearly 900 eligible patients from 14 countries, including Korea, and the final results are still pending.[54)]

The 5G technologies using electromagnetic waves can make hyper-connected network environments capable of augmented reality and three-dimensional service. The 5G frequency comprises 3.5-GHz and 28-GHz bands. The effect of the 3.5-GHz band on humans may be similar to that of 4G and can utilize the existing base station, but 28 GHz may be different to the human body and the base stations must be installed more closely. Therefore, children using 5G technologies should be carefully examined. The impact of 5G technologies on children has never been evaluated.[55)]

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Precautionary principles for children

International policies and advisory responses regarding children's exposure to RF-EMF vary. RF-EMF–related advisory policies for children are as follows: banning mobile phone advertising or sale to children, SAR labeling, and preferring wired connection to WiFi in schools. In Korea, only the policy of SAR labeling on mobile phone is strictly followed. Similar to other scientific uncertainties, precautionary principles should be followed for the EMF problem (EC, 2017).[56)] The meaning of precautionary principle is as follows: w*hen human activities may lead to morally unacceptable harm that is scientifically plausible but uncertain, actions shall be taken* to *avoid or diminish that harm (UNESCO 2015).* For children, strict standards are required until scientific knowledge is established, specifically in facilities such as schools and preschools, where they stay longer. This article suggests precautions to reduce the risk of excessive EMF exposure in children (Table 1).

Conclusion

The nervous systems of children are more vulnerable to the effects of electromagnetic waves than those of adults. Although studies on the effects of EMFs on children's health are unestablished, precautionary principles should be followed for children and the exposure to EMFs among children should be minimized. The fact that EMFs are possibly carcinogenic according to the IARC should not be overlooked or interpreted with bias, and the opinions of clinicians should be given more weight than those of industries in the establishment of safety policies for EMF use. Moreover, a study that assesses the effects of 5G frequency technology on children's health is required.

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Conflicts of interest

The author declares no conflicts of interest.

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Figure legends

Fig. 1.

The electromagnetic spectrum. Frequencies (expressed by hertz, Hz) increase from left to right, while wavelengths decrease from right to left. Ionizing radiations are x-rays and *r*-rays. EHF, extremely high frequency; HF, high frequency; LF, low frequency; MF, medium frequency; SHF, super-high frequency; VF, voice frequency; VHF, very high frequency; VLF, very low frequency; UHF, ultra-high frequency

Fig. 2.

Various sources of electromagnetic fields (EMFs). Extremely low frequency EMFs (ELF-EMFs) are generated by electricity, various home appliances, in-house wiring, and outside high-voltage lines. Radio frequency EMFs (RF-EMFs) waves are generated by mobile phones, smart devices, WiFi, base stations, and other devices.

Fig. 3.

The vulnerability of children to electromagnetic field exposure according to the UK Independent Expert Group on Mobile Phones.

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Table 1. Precautions to reduce the risk of excessive EMF exposure in children

Children can be exposed to EMF by electronic devices, high-voltage transmission lines, mobile phones, WiFi, etc.

For parents:

- Avoid long-term exposure to strong EMFs in home, school, or other places children spend much of their time.
- Avoid using electrical devices within 30 cm of the body.
- Avoid using smartphones directly against your child's head.
- Keep your child's body from getting hot while using mobile phones.
- Do not allow your child to use smart devices during meals or for the last hour before bed.
- Note that the effects of various devices using virtual reality and WiFi have on the neural development of children remain unknown.
- Most products that claim to reduce EMFs are ineffective or unproven.
- Ask your child's pediatrician for information to guide your child's use of smart devices.

For teachers, policymakers, and commercial companies:

- Teachers: Educate children on how to avoid excessive EMF exposure.
- Policymakers: Create policies to reduce children's EMF exposure from the environment.
- Commercial companies: Create products that reduce children's exposure to EMFs and issue warnings about them.

EMFs, electromagnetic fields

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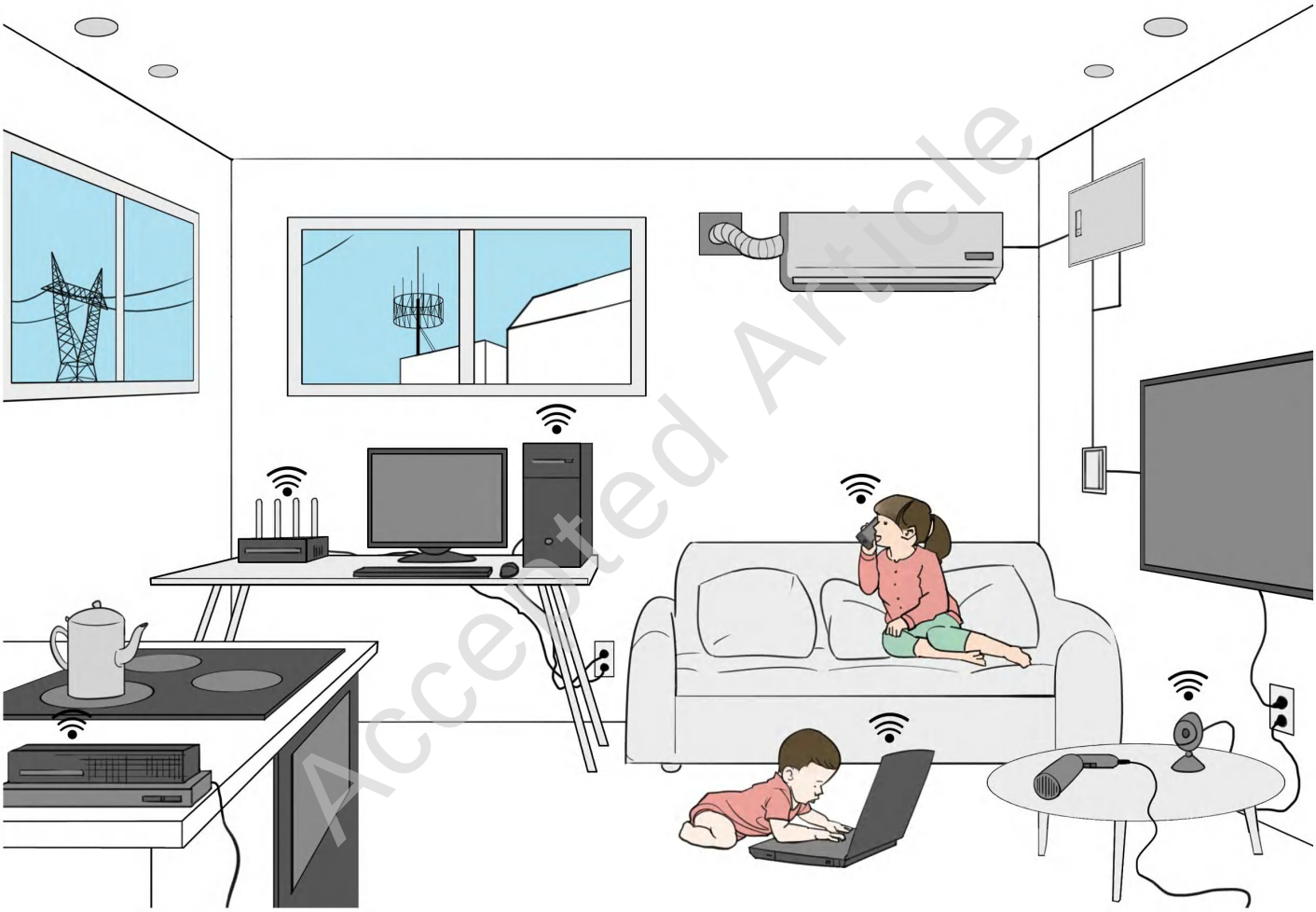

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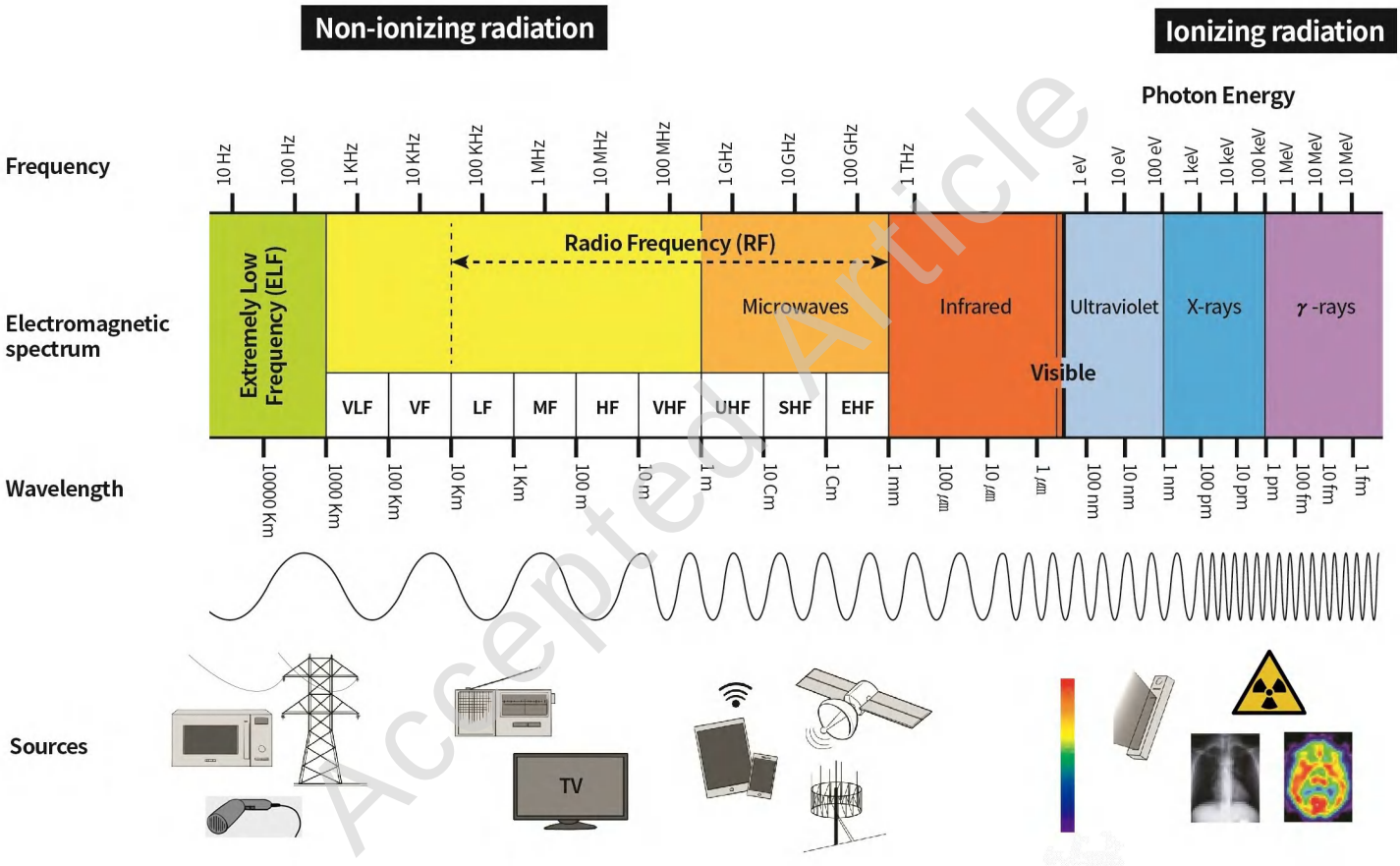

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Fig 3

Children may be more vulnerable to EMF than any other age groups.

- *Children are exposed to electromagnetic waves over a longer life time than adults.*
- *Their nervous systems are in the process of development.*
- *The conductivity of the children is higher due to higher moisture and ionic content than adults.*
- *Children's head absorbs a lot of RF energy more than adults.*

From "Stewart report" by the UK Independent Expert Group on Mobile Phones (2000) [4)]

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A Report on the Non-Thermal Effects of Radio Frequency Radiation and the Adequacy of Health and Safety Guidelines to Protect Public Health

Professor Tom Butler

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A Report on the Non-Thermal Effects of Radio Frequency Radiation and the Adequacy of Health and Safety Guidelines to Protect Public Health

The purpose of this Expert Report is to provide objective answers to the following two questions:

1. What are the findings of peer-reviewed scientific studies on the non-thermal effects of RFR and the implications for human health and well-being?
2. Can the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and its guidelines (ICNIRP, 1998, 2020) be trusted to protect public health?

Duty to the Court

I understand that my duty to the Court is to provide independent assistance to the Court on matters within my expertise and that it overrides any obligation to the person from whom I have received my instructions, or by whom I am paid. I have complied with this duty. I am also aware of the requirements of Part 35 CPR, Practice Direction 35, and the Guidance for the Instruction of Experts in Civil Claims 2014.

Statement of Truth

I confirm that I have made clear which facts and matters referred to in this report are within my knowledge and which are not. Those that are within my knowledge I confirm to be true. The opinions I have expressed represent my true and complete professional opinions on the matters to which they refer. I, Professor Thomas Butler, declare as the maker of the above statement that I believe the contents to be true and understand that it may be placed before the Court.

Expert Details and Qualifications

Thomas (Tom) Butler PhD MSc is a Professor of Information Systems (IS) at University College Cork, Ireland. A former satellite and microwave telecommunications engineer, Tom teaches a range of computing (including data communications and WiFi) and informatics courses at all levels. Of special import are his seminars on the scientific method and philosophy of science to PhDs. He has over 200 publications in the IS field's leading journals and conferences and a range of other outlets. Tom has garnered over €8.5m in research funding in the past 15 years and has several technological innovations to his name. In 2015, Tom began researching the risks posed by wireless technologies to children, following a suggestion by the Chief Risk Officer concerned about the impact of Wifi on children. Tom is now part of an international community of scientists, all experts in their fields of epidemiology, oncology, biology, bioelectromagnetics, medicine, physics, electrical and electronic engineering, and so on, and is regarded as one who can communicate the findings of multi-disciplinary research to policymakers and the public in an unbiased and accessible manner.

A Report on the Non-Thermal Effects of Radio Frequency Radiation and the Adequacy of Health and Safety Guidelines to Protect Public Health

Executive Summary

The majority of peer-reviewed scientific studies conclude that human health and well-being are under significant threat from everyday wireless technologies: these include existing 2-to-4G, Wifi, and Bluetooth—5G magnifies these risks substantially. The past 15 years have seen the proliferation of non-ionizing radio frequency radiation (RFR[1]) devices and related communication systems in the home, school, workplace, and across the environment. The safety standards for all RFR sources are based on the accepted harmful thermal effects of microwave RFR: however, independent research demonstrates that the telecommunications and technology industries have, from the outset, ignored or denied the existence of non-thermal effects. All this despite a comprehensive review of research published between 1969-1976 by the U.S. Naval Medical Research Institute (MNRI) (Glaser et al., 1976). This extensive bibliography of over 3,700 studies demonstrated from the outset the equally harmful non-thermal effects of RFR, including its potential to cause cancers, neurological, neurodegenerative, and other pathophysiological problems.

Since 1976, thousands of independent research studies, *in vitro*, *in vivo,* and epidemiological, demonstrate that low-intensity RFR elicits a range of physical and biological effects, including pathophysiological effects, in experimental animals and humans. The overwhelming majority of peer-reviewed studies find such effects. The last five years have seen an increase in the volume and velocity of scientific studies finding significant risk in non-thermal effects of near-field and far-field on humans, culminating in the *"clear evidence"* of carcinogenicity in the US National Toxicology Programme (NTP, 2018a,b) and Ramazzini Institute studies (Falcioni et al., 2018), for examples. This significant body of research places in question the safety of 5G technology and the risks it poses to humans and the biosphere.

The public awareness and disquiet regarding 5G have focused on far-field non-thermal effects: However, in my opinion, based on the findings of extant research, the multiplicity of near-field devices poses even greater risks to human health and wellbeing. Peer-reviewed scientific studies find that 3-4G telecommunication devices, 2-5G Wifi devices, and the now ubiquitous Bluetooth devices, pose significant threats risks to adults, children, and the unborn. These risks occur at much lower levels of RFR power density than the thermal safety guidelines permit. It has been known for decades that the central nervous system (CNS) is at greatest risk from RFR, with altered neurotransmitter function, cellular signaling problems, blood-brain barrier breakdown, neurological and neurodegenerative disease, oxidative stress, impairment of human reproduction systems, apoptosis, and cellular DNA damage, among a range of serious health effects identified in the scientific literature. The introduction of 5G technologies may raise the risks for many in the population to unsustainable levels. Significantly, 5G may also bring new threats, as in addition to the low- and high-frequency RFRs in existing technologies linked with

[1] Radiofrequency radiation (RFR) is a type of non-ionizing radiation (NIR), which is also referred to as radiofrequency (RF) electromagnetic fields (EMFs). RF EMFs are in the frequency range 100 KHz to 300 GHz, this includes all 2-5G, WiFi and Bluetooth technologies. In the UK, 5G technologies will emit RFR (RF EMF) in the frequency 700 MHz-28GHz, and beyond. In keeping with relevant research papers, this report employs the term RFR, as opposed to RF EMF or simply EMF.

the afore-mentioned conditions, 5G will almost certainly introduce untested exposures to extremely high frequencies. Scientists argue that this may expose skin and eyes to major immunologic and other systemic risks. Unfortunately, policymakers and regulators appear not to understand the difference between the type and strength of scientific evidence required to demonstrate causality and the level of evidence necessary to invoke the precautionary principle and mitigate risks to human health and well-being (cf. Gee, 2008).

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) conveniently ignores scientific concern on the interaction between 5G's extremely high frequencies and complex biological role of human and animal skin, and the skin's role in the immune system. Also, UK policymakers appear not to comprehend the health implications. As this report demonstrates, there is a range of unknown risks here, which require intensive research. Take, for example, a recent review study funded by Deutsche Telecom catalogued just two studies that investigated the 5G extremely high-frequency range being deployed in the UK (Simkó and Mattsson, 2019). The reported studies found adverse physical and biological effects. However, general studies on extremely high frequency also posit significant risks to insect life, especially bees. The scale and import of extant research on all aspects of electromagnetic fields (EMF), including RFR is significant (Kostoff, 2020). The Research Center for Bioelectromagnetic Interaction at Germany's Aachen University catalogs 142 papers related to various technical, dosimetric, and miscellaneous aspects of 5G in its EMF Portal[2]: However, it is clear that there is a paucity of research on the health risks to humans on current extremely high-frequency 5G.

Significantly, extant research on RFR from all existing sources can help to inform the identification and assessment of 5G risks (Di Ciaula, 2018; Miligi, 2019; Russell, 2018; Kostoff et al. 2020; Barnes and Greenebaum, 2020). As of June 2020, Aachen University's EMF Portal catalogs 31,329 publications and 6,734 summaries of individual scientific studies on electromagnetic fields, with an estimated 1,892 studies on RFR. A more comprehensive database on RFR is that curated by Oceania Radiofrequency Scientific Advisory Association Inc. (ORSAA): Its database catalogs 3,671 studies on RFR research.[3] A recent analysis of scientific studies on the physical and biological effects of RFR in that database found the following: *"There are 3 times more biological "Effect" than "No Effect" papers; nearly a third of papers provide no funding statement; industry-funded studies more often than not find "No Effect", while institutional funding commonly reveal "Effects""* (Leach et al. 2018). Simply put, 68% of peer-reviewed scientific research studies, or the majority view, find physical and biological non-thermal effects, while only 32% of studies, the minority position articulated by industry scientists, find no evidence of non-thermal effects. Thus, in keeping with research findings on industry studies on environmental toxins and carcinogens generally, there is a clear pattern of bias, selective reporting, and misreporting by industry and related organisations such as the ICNIRP (see Michaels, 2008, 2009; Maisch, 2009; Oreskes and Conway, 2011; Walker, 2017). What are the implications of all this for the deployment of 5G? A recent research review on the risks to human health of RFR, concludes that *"the literature shows there is much valid reason for concern about potential adverse health effects from both 4G and 5G technology"*: however, even extant findings *"should be viewed as extremely conservative, substantially underestimating the adverse impacts of this new technology"* (Kostoff et al. 2020).

It is, therefore, puzzling why the UK government failed to recognize this body of research and take appropriate action to protect its citizens from what are very real health risks. One

[2] www.emf-portal.org

[3] Oceania Radiofrequency Scientific Advisory Association Inc. / https://www.orsaa.org/

explanation for this is that the UK government accepts uncritically what is the minority scientific view, which emanates from the ICNIRP. ICNIRP is an NGO characterized by poor governance, traditionally close ties to industry, no independent oversight, insufficient expertise in key areas, and no accounting for its funding (Buchner and Rivasi, 2020). Indeed, it's annual reports should be a cause for alarm, given the paucity of funding reported (e.g. its annual income was €133,254.20 for 2018). A major question begs as to how the ICNIRP can fund its many activities and deliver high quality, reliable, and accurate research outputs and guidelines to inform government policy? This is not an insignificant issue as the ICNIRP has not been transparent about its activities nor its income. Every government agency in Europe looks to the ICNIRP for guidelines. How can this organisation do what it claims to do when its income is less than that of a senior civil servant? To reiterate, the cumulative body of scientific evidence from several hundred experts in the fields of epidemiology, medicine, and bioelectromagnetics stands in polar opposite to the conclusions of ICNIRP, whose 13 commissioners, along with industry-funded scientists, present what is, as described, a minority view (Buchner and Rivasi, 2020). As will be seen, this minority view continues to influence key decisions by other bodies such as the World Health Organization (WHO), the International Agency for Research on Cancer (IARC), and the EU's Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), and influenced the UK's Advisory Group on Non-ionising Radiation (AGNIR). The mechanism for this is simply that ICNIRP members play key or dominant roles in relevant decision-making processes and the drafting of periodic reports issued by each of these organisations or committees. To have ICNIRP scientists drafting safety guidelines while also acting as members of expert groups responsible for objectively assessing those safety guidelines is anathema to all principles of good governance. It is akin to academics acting as authors and reviewers of their scientific papers. No other area of scientific endeavor would countenance such conflicts of interest or lack of independence.

For all of the above reasons, it is my opinion that UK policymakers were remiss in not seeking the advice of an independent multidisciplinary panel of international scientists to conduct a study of the health and environmental implications of RFR, particularly as it relates to 5G. The outcome of such a review may have produced a biologically-based exposure standard, reflecting both the precautionary principle and the radiological practice of exposures that conform to the ALARA principle (As Low As Reasonably Achievable). This standard would have taken account of key variables such as the intensity, frequency, and duration of exposure to harmful RFR. This, unfortunately, did not happen. However, the Realpolitik of the government approach is summed up in the following statement from a fellow scientist: *"years ago when working on committees with top level UK Department of Health officers, I was told "before we recognise EMF and RFR as a problem, you will need to have bodies on the streets and in the wards."* If this is the starting point for UK policymaking on the protection of public health, then there are serious questions to be answered.

Given the evidence presented, this report concludes that the UK government may have failed in its duty to identify, assess, and mitigate the risks posed by RFR-based technologies, including 5G, before their introduction, with implications for the protection of public health. It also provides evidence that the processes by which policy decisions have been made concerning the protection of public health may be significantly flawed, as the overwhelming body of scientific evidence appears to have been ignored by relevant government departments and agencies in arriving at decisions about the introduction of 5G and similar technologies.

1. INTRODUCTION

While mobile phones have been in widespread use for over 25 years, the last 15 years have witnessed the proliferation of near-field microwave non-ionizing Radio Frequency Radiation (RFR) devices in the home, school, workplace, hospital, and society. However, far-field RFR from WiFi access points (AP) and routers, and at a wider level, 2, 3, 4, and 5G cellular telecommunications antennae, also pose significant risks, as the overwhelming body of extant scientific research indicates.

The cumulative body of research, which includes scientific findings from laboratory experiments (*in vitro* and *in vivo*) and epidemiological studies, provides *"clear evidence"* of the threats to human health and well-being from RFR (Belpomme et al., 2018). The health and well-being of children are particularly at risk when the safety guideline was developed and RFR-based technologies deployed for use (Morgan et al., 2014).

The following sections of this report address several questions:

1. What are the findings of peer-reviewed scientific studies on the non-thermal effects of RFR and the implications for human health and well-being?
2. Can the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and its guidelines (ICNIRP, 1998, 2020) be trusted to protect public health?

This report begins with a short history to help the reader understand that current concerns are not new, and as with other environmental toxins such as asbestos and tobacco smoke, RFR has been of concern to scientists for some time.

A short history of scientific research on microwave RFR

The significant clinical and biological effects of RFR were identified by naval researchers in their review of Soviet and Eastern-Bloc studies at a symposium in 1969 (Dodge, 1969). Subsequently, in 1976, the US Naval Medical Research Institute published a bibliography of 3,700 scientific papers on the thermal and non-thermal biological effects of RFR (Glaser et al. 1976)[4]: this was the last of a series of supplements to the original report in 1972 (Glaser et al. 1972).

In summary, the NMRI identified the following findings:

- Thermal effects identified include heating of the whole body, brain, eyes, testicles, and sinuses, among others.
- Non-thermal effects identified include oxidative process change (a precursor for DNA strand breaks and ultimately cancer), decreased fertility, altered fetal development, muscle contraction, cardiovascular changes, altered menstrual activity, liver enlargement, changes in conditioned reflexes, and so on.

The US Office of Telecommunications Policy began its *Program for control of electromagnetic pollution of the environment: the assessment of biological hazards of nonionizing electromagnetic radiation* in 1970 (Healer, 1970). Four reports were issued during the 1970s until government reorganization in 1978 saw the Department of Commerce and the National Telecommunications and Information Administration replace the Office of Telecommunications Policy. The *"NTIA is the Executive Branch agency that is principally responsible for advising the President on telecommunications and information policy issues."* The fifth and final report of the Program was published in 1979: this body of work built on that by the NMRI and voiced concern on the health

[4] https://ehtrust.org/wp-content/uploads/Naval-MRI-Glaser-Report-1976.pdf

implications of human exposure to RFR. It concluded on the need for a comprehensive research programme to protect public health, with the EPA to continue its programme of research on biological effects (NITA, 1979).

In 1973, a review and study by Russian scientists on the effects of low-intensity RFR on experimental animals indicated clear evidence of effects on the brain and nervous system, and also the heart and testes, of subjects (Tolgskaya and Gordon, 1973). Historically, Russia has more stringent safety standards than the West, whether it is the EU or US when it comes to RFR.

The thermal-only safety levels for RFR in the US and Europe were determined by the US military-industrial complex viz. *"the military dominated the scientific discussion on safety limits and science, already aware of the possible health hazards at that time, fell by the wayside. In agreement with the U.S. Government, the U.S. Armed Forces – supported by the microwave industry – established safety limits according to military requirements without taking much care of possible health concerns. At the same time they shielded the Government, which was not ready to openly take over the responsibility for this development, since it was afraid of negative consequences from the public opinion"* (Adlkofer, 2015: cf. Cook et al. 1980; Becker and Selden, 1985; Steneck, 1987).

In 1981, the pro-business Regan Administration *"launched an overt attack on the EPA, combining deregulation with budget and staff cuts"* (Fredrickson et al. 2018). Hence, the *"trend toward stricter controls on activities perceived as harmful to public health"* (David, 1980) either plateaued or went into reverse. Certainly, the *Program for control of electromagnetic pollution of the environment* appears to have been set aside: This program, like the EPA and the *Clear Air Act,* was instituted by the Nixon Administration. The Act and the EPA and have, to this day, been targeted by successive presidents, even democrats, due to industry lobbying and influence (Alster, 2015).

Other agencies such as the US Department of Energy and NASA continued their interest in research on the health risks of RFR. In a report that looked at standards, the Department of Energy researcher Leonard David (1980) concluded that *"To a large degree, discrepancies between Eastern and Western microwave standards are due to contrasting philosophies. For the U.S. the concept of risk/benefit criterion has been accepted, involving use of an adequate safety margin below a known threshold of hazard. On the other hand, Soviet and most East European microwave standards are based on a "no effect" philosophy-all deviations from normal are hazardous."* This captures well the approaches of the two camps of scientists today—those who claim that thermal effects pose the only threat to humans, while those who find evidence of non-thermal effects at much lower levels of RFR intensity and concomitant physical and biological effects.

David (ibid.) adds that *"Divergent findings of Western and Eastern scientists regarding bioeffects of microwave irradiation have resulted in dissimilar standards, guidelines and recommendations for limiting human exposures. These standards differ markedly, as evidenced by the maximum RFEM radiation intensity of 10 mW /cm2 in effect in the United States, compared with 0.01 mW/cm2 for the same exposure duration in the U.S.S.R.--a level 1000 times lower."* It is important to note that the US standard, which was adopted by the Western countries, including the UK, was *"established from theoretical calculations on the amount of exogenous thermal loading that can be tolerated and dissipated by the body without a harmful rise in body temperature."* It is interesting to note that David (1980) finds: *"Maximum East European exposure levels for microwaves, on the other hand, have been based primarily on reported central nervous system (CNS) and behavioral responses. Bolstered by epidemiologic studies, microwave exposure standards for most Soviet Bloc and East European nations are founded, with*

minor variations, on limits established by the U.S.S.R." Thus, the general approach of Western scientists was initially theory-based, while Eastern scientists looked to empirical evidence. The majority of scientists now find evidence of non-thermal effects from empirical studies.

In a study by NASA, Raines (1981) points out that *"both theories and observations link nonionizing electromagnetic fields to cancer in humans, in at least three different ways: as a cause, as a means of detection, and as an effective treatment."* Raines catalogues other biological effects, as did the EPA's (1984) major study. Based on a subset of the literature, the EPA nevertheless concluded that *"the currently available literature on RF radiation provides evidence that biological effects occur at an SAR[5] of about 1 W/kg; some of them may be significant under certain environmental conditions."* This stands in stark contrast with the ICNIRP (2020) guidelines which *"adopted a conservative position and uses 4 W kg−1 averaged over 30 min as the radiofrequency EMF exposure level corresponding to a body core temperature rise of 1°C."*

It is interesting to note that the EPA continued to investigate the non-thermal effects until the research was defunded in 1996. In 1990 a comprehensive peer-review study its researchers categorized EMFs as *"a possible, but not proven, cause of cancer in humans"* (McGaughy et al., 1990). Thus, from 1975 to 1995, the EPA conducted a research program on electromagnetic fields (EMF), including RFR, and were about to develop EMF safety standards, before it was de-funded in 1995.

Independent research continued to produce evidence of health risks from non-thermal exposure to low-intensity RFR (see for examples: Lai et al., 1986; De Guire, 1988; Kolmodin-Hedman et al., 1988; Kolomytkin et al. 1994; Grayson et al., 1996; Kolodynski and Kolodynska, 1996; Lai and Singh, 1995, 1996). While this research was important, the testimony of former Motorola Engineer R.C. Kane was more significant from a public perspective. The late Mr. Kane, who died from brain cancer linked with his work on mobile phones, published a whistleblower's account as a book titled, *Cellular Telephone Russian Roulette* in 2001 (Kane, 2001). The same year, another industry whistleblower, Dr. George Carlo published an explosive account of industry dishonesty and manipulation, titled "Cell Phones: Invisible *Hazards in the Wireless Age: an Insider's Alarming Discoveries about Cancer and Genetic Damage*"(Carlo and Schram, 2001). Significantly, from 1995, Dr. Carlo directed the industry-financed Wireless Technology Research (WTR) project using $28.5m funding. The purpose of this initiative was to counter the EPA's findings and the growing body of research conducted by independent scientists. Its findings were rejected by the industry, as they confirmed the significant health risks from RFR. Following this, Dr. Carlo's services were immediately dispensed and he subsequently published an account of industry dishonesty and manipulation, titled *Cell Phones: Invisible Hazards in the Wireless Age: an Insider's Alarming Discoveries about Cancer and Genetic Damage* (Carlo and Schram, 2001). This was not the only account of industry misconduct and political manipulation to occur during the 1990s (See Alster, 2015; Adlkofer, 2015).

The body of scientific evidence on the health implications of the non-thermal effects of RFR has grown exponentially since. Nevertheless, the early evidence provided by Russian scientists and their contemporaries in the US and Europe should have given pause to the telecommunications industry, regulators, and policymakers concerning the commericalisation and widespread use of mobile telephony in the 1980s and 1990s. However, as will be shown, the telecommunications and technology industries acted to secure the future commercial success of wireless RFR information and communication technologies (ICT), at the expense of public health, by learning

[5] *"Specific Absorption Rate (SAR) The rate at which energy is absorbed into the tissue in watts per kilogram."* (EPA, 1984).

from other environmental polluters (Alster, 2015; Michaels, 2008). Michaels (2008) illustrates how the tobacco and petrochemical industries hired scientists and commissioned papers to cast doubt on epidemiological and laboratory evidence on the risks to human health of smoking.

As with these industries, the telecommunications and technology sectors sowed doubt about science and medical facts about the health risks to neutalise regulatory and public concerns about the health risks of RFR. They went a couple of steps further, however: Through the ICNIRP, and its founding chairman Michael Repacholi, industry (and ICNIRP) scientists infiltrated the WHO, gaining credibility and then captured the Federal Communications Commission (FCC) (Alster, 2015; Adlkofer, 2015). Professor Franz Adlkofer (2015) states that *"A milestone in putting through the interests of the mobile communication industry was the establishment of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) in 1992. It is a non-governmental organization. Michael Repacholi, then head of the WHO's EMF Project, managed to get official recognition for this group by the WHO as well as the EU and a series of its member states, among them Germany. Repacholi, first ICNIRP chairman and later emeritus – member, left the WHO after allegations of corruption in 2006 and found a new position as a consultant to an American electricity provider."* Adlkofer (2014) adds that when the ICNIRP *"established the European safety limits it uncritically based its decision on Schwan's pseudo-theorem [of 10 mW /cm2]. The American safety limits were taken over with only minor alterations"* (see ICNIRP, 2009).

Thus, through lobbyists, law firms, consulting scientists, targeted scientific research funding and the co-optation of pseudo-independent organisations such as the ICNIRP and captured agencies and organisations such as the FCC and the WHO, the health risks of RFR have been disputed and scientific findings undermined using what Michaels terms *"junk science"* (Huber, 1993; Michaels, 2008, 2008; Walker, 2017). During the 1990s and since this involved the perverse and biased application of epidemiological approaches and statistical methods to reinterpret valid scientific data to arrive at conclusions that support the industry view of no harm or effect. Proof of this comes from Dr. Neil Cherry in his report on the ICNIRP (1998) Guidelines to the New Zealand Ministry of Health and Ministry for the Environment before their adoption (Cherry, 2004). Dr Cherry termed the manner in which the ICNIRP-WHO treated extant findings as *"The Constructive Dismissal Approach"*. He stated that *"In order to maintain the RF-Thermal View against the extremely strong evidence from epidemiology, animal experiments and of non-thermal mechanisms, the WHO and ICNIRP assessors and their colleagues have developed a set of dismissive methodologies. These include:*

- *Maintaining that the RF-Thermal view as the "consensus of science". This allows the biological mechanism to dominate and epidemiology and animal evidence is dismissed.*
- *Maintaining a contrast between Ionizing radiation and Non-ionizing radiation.*
- *Moving the level of evidence goalpost where for a study to become "evidence" it must first be replicated, whereas in the past each study was evidence and replication was required to "establish" a biological effect.*
- *Promoting strict sets of scientific criteria which are proposed as being necessary for reliable use of the results, e.g. the Bradford Hill "criteria", instead of "viewpoints", and Dr Martin Meltz's 13 experimental criteria for testing genotoxicity (Meltz, 1995). In this way all non-thermal evidence is rejected.*
- *Citing studies which are too small and have small follow-up periods so there is little or no opportunity for cancer to develop, as evidence that radar [RFR] exposure does not cause cancer.*
- *Citing studies which do show significant increases in cancer as showing no evidence of increases in cancer.*

- *Preferring to simply quote the conclusions of papers and reports that state that there were no adverse effects found, while failing to recognize that the data and analysis within the documents do show significant associations, including significant dose response relationships.*
- *Dismissing epidemiological studies on the grounds that populations and exposures are not well defined. Lilienfeld explains that this is a difficulty but results are still relevant and important. (Lilienfeld et al. 1978).*
- *Dismissing research results one by one and failing to assemble and interpret the whole pattern of research results - the divide to conquer approach.*

All of these are demonstrated methods used by WHO and ICNIRP which amounts to a systematic approach to wrongly dismiss evidence of effects, i.e. Constructive Dismissal."

Early evidence of this comes from the controversial research at The Royal Adelaide Hospital in South Australia. Fist (1999) reports that it *"conducted two parallel studies on EMF exposure between 1993 and 1995. The research design was checked by a committee of the National Health and Medical Research Council (NHMRC) of Australia (the supreme medical research authority) and the hospital had a special committee supposedly oversighting the day to day activities.*

The promoter of these two research projects, Dr Michael Repacholi (now in charge of WHO's EMF project in Geneva) sold the idea to the electricity supply organisation and cellphone industry as a way to solve their problems once and for all.

Repacholi is not so much a scientist (he has no research credentials before this), but is well-known as a spokesman and science administrator. He has long been one of the world's best known and most vocal "No Possible Effects" promoters for both low-frequency mains power and cellphones and therefore had the confidence of both the ESAA and Telstra." The mobile phone study was funded by *"Telstra (Australia's dominant carrier) to look specifically at possible effects of GSM digital cellphone exposures."*

The GSM study was rigorous and *"had control groups of 100 animals, which were treated identically (down to the use of "sham" exposures), and both were double-blind trials where no one knew which autopsied mice had been exposed and which had not until after the diagnosis of cancer had been determined."* The study's findings were published in Radiation Research in 1997, concomitant with the development of the ICNIRP guidelines published in 1998. This study led by the Chair Emeritus of the ICNIRP, *"established clearly and with little room for doubt that the industry claim that "cellphone radiation cannot possibly affect biological tissue at non-thermal exposure levels," is a complete lie. And this finding is only one of hundreds which have consistently shown this, with varying degrees of validity and credibility over many years. It fits almost perfectly into the overall "assemblage" of evidence accumulated by many different independent biomedical researchers from many varied studies on animals and cell-cultures"* (Fist, 1999). The study reported that *"Lymphoma risk was found to be significantly higher in the exposed mice than in the controls (OR = 2.4, P = 0.006, 95% CI = 1.3-4.5). Follicular lymphomas were the major contributor to the increased tumor incidence. Thus long-term intermittent exposure to RF fields can enhance the probability that mice carrying a lymphomagenic oncogene will develop lymphomas"* (Repacholi et al. 1997). That is, exposed mice were 2.4 times more likely to develop lymphomas than controls.

This extended extract from Fist's statement to the Select Committee on Science and Technology is revealing:

"What interests me here is the way in which the release of the information was manipulated—by the scientists, by the hospital, and by the ESAA and Telstra (it is often not clear which)—and sometimes by all of them together.

Remember, two and a half years after the completion of the study, not one word of results had leaked out. In the interim, Dr Repacholi had attended dozens of conferences and given dozens of interviews, and still vocally maintained his stance that there was no evidence connecting cellphone exposures to adverse health consequences—knowing all the time that his mice had shown a major, highly significant, increase in basal-cell lymphomas.

Yet Michael Repacholi told me off-the-record at a London Conference on 15 November 1997 (it is recorded in my journalist's notebook) that the research had turned up "nothing of any significance". … At the same London conference, he was very vocal in supporting industry claims that there were no studies linking cellphones to adverse health effects and strongly criticised a few scientists who had turned up positive results. There were dozens of people at the conference who can attest to this.

At this time Dr Repacholi was the head of WHO's EMF Project and probably the second most powerful cell-research-funding bureaucrat in the world (Dr George Carlo was the most powerful)—yet he was publicly denying and discounting his own unpublished research.

At that time Repacholi had known for over two years that the Adelaide Hospital research finding was the most significant link yet discovered. It had a "highly significant" p-value, and an Odds Ratio (OR) of 0.999—meaning that this doubling of leukemia in the exposed mice could only have arisen by chance once in a thousand experiments. This is 10 times more significant than the normal 1 per cent "high-significance" level in a very well-conducted live animal trial."

Research in organisations notes the impact of the founders and leaders in shaping an organisations culture, values, and commitment (Selznick, 2011; Morely et al. 1991). Thus, there is abundant evidence that ICNIRP, as the creation of Michael Repacholi, implemented his values and beliefs and this is evident in the thermal only view on the physical and biological effects of RFR that is evident to this day. It is also apparent that such values and beliefs dominate in fora in which ICNIRP members participate. Take, for examples, that critical peer-reviews of ICNIRP Guidelines and reports where ICNIRP Commissioners and Expert Advisors participated (e.g., WHO and European Commission— EU's Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), and the UK's Advisory Group on Non-ionising Radiation (AGNIR)) all exhibit the same pattern of *"constructive dismissal"* tactics described in initially by Cherry (2004): the see the following peer-reviewed papers (Maisch, 2009; Adlkofer, 2015; Sage et al., 2016; Starkey, 2016; Hardell, 2017; Carlberg and Hardell, 2017; Walker, 2017; Pockett, 2019; Hardell and Nyberg, 2020; Melnick, 2020; Buchner and Rivasi, 2020).

Reflecting on these historical facts and current realities, several questions beg:

1. If the US Navy NMRI in 1971 identified, based on over 2,000 studies on RFR, 9 thermal effects, and the 43 non-thermal effects viz. 29 physiological effects, 9 CNS effects, and 5 autonomic and peripheral nervous system, why do the industry, ICNIRP, and policymakers persist in the denial of non-thermal effects given the findings of thousands of studies since?
2. If EPA scientists found EMFs to be a possible carcinogen and probably responsible for a range of physical and biological effects in 1990, why did the industry, ICNIRP, and policymakers adopt the position that there was no evidence of non-thermal physical or biological effects?

This report addresses these questions below. It first considers the overwhelming scientific evidence that has accumulated over the past 20 years.

2. WHAT DOES EXTANT, PEER-REVIEWED SCIENTIFIC RESEARCH HAVE TO SAY ABOUT THE PHYSICAL AND BIOLOGICAL EFFECTS OF RFR?

Not a single, peer-reviewed scientific study has been carried out to assess the health risks associated with 5G technologies as they are being deployed in actual human environments. Furthermore, they are to be deployed in concert with existing 2-4G technologies and other RFR sources, such as WiFi etc., all of which have been found to increase the risk of disease in animals and ill-health in humans. Incredible as it may sound, industry scientists, and those at the ICNIRP, failed to conduct or commission, a single *in vitro* or *in vivo* study on what are, in the round, novel technologies, whose predecessors have known physical and biological non-thermal effects. Before exploring these effects, a short introduction to the technology in question and how it relates to previous technologies is presented.

A technical note on 5G technologies

5G technologies emit low frequency (700MHz), high frequency (3.4-3.8 GHz, centimetre (CM)) or extremely high-frequency millimeter (MM) (26 GHz and above) RFR. The low and high frequencies planned in 5G are similar to those used in 2-4G. It is important to note that these frequencies will be transmitted from both far-field antennae in base-stations and, also, from all forms of user equipment in the environment: smartphones and all wireless devices in the Internet of Things (IoT).

5G builds on 4G and WiFi technologies, in that they share the same basic approach to modulation viz. orthogonal frequency-division multiplexing (OFDM). As with 4G, 3G, and WiFi, 5g employs multiple-input multiple-output (MIMO) transmission techniques. The 5G implementation is called massive MIMO (mMIMO); however, 5G's approach is technically sophisticated and innovative.

OFDM is a signal transmission approach that uses a large number of closely-spaced carriers modulated with low data rates. OFDM permits spectral efficiency scheme (i.e. efficiency in the use of the available frequency spectrum) which enables high data rates and permitting multiple users to share a common transmission channel.

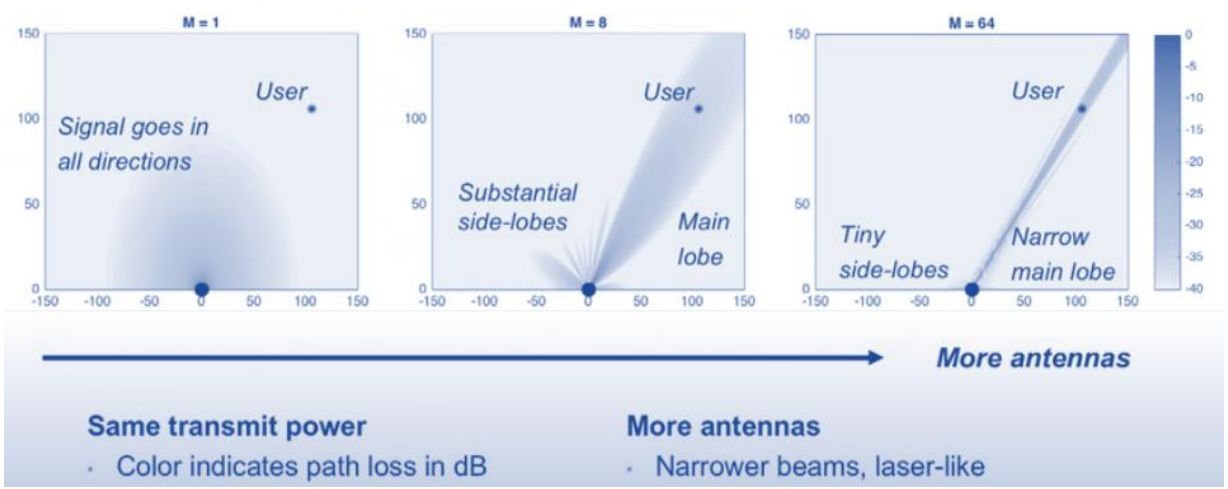

Figure 1 Traditional vs. mMMIO Beamforming Techniques

Figure 2 Signal Diversity

MIMO schemes improve data throughput and enable further spectral efficiency by using multiple antennas at the transmitter and receiver. This is an approach to increasing the capacity of a radio link using multiple transmission and receiving antennae to take advantage of multipath propagation. Accordingly, it uses complex digital signal processing to set up multiple data streams on the same channel. MassiveMIMO (mMIMO) typically implements an array up to hundreds of antenna elements serving user equipment (e.g. smartphones and other devices, such as IoT, including autonomous vehicles) using reciprocity-based multi-user or MU-MIMO.

5G's mMIMO employs beamforming, beam steering, and beam switching. Traditional base station antennae radiate signals over a wide area (M=1 in the above figure). Typical deployments provide cover like the beam from a reading lamp over a desk. The entire desk is illuminated when only a specific paper or book requires illumination. Others are like radio station antennae, which are in comparison like naked light bulbs, radiating in all directions enabling a book to be read anywhere in a room. The light energy weakens the further away from the source, as does the RFR signal energy the further away from a base station antennae. Like a high power torch or searchlight, a focused beam illuminates only what it is pointed at and therefore saves energy. This is the principle underpinning beamforming plus beam steering.

Beamforming uses multiple antennas to control the direction of signal transmission through complex digital signal processing techniques using individual antenna signals in an array of multiple antennas. Beam steering allows a signal beam to be targeted at a specific receiver or user equipment in a specific direction. Different signal beams can also be targeted in different directions to serve multiple users or EUs. A 5G base station performs dynamic calculations to effectively track users using beams, switching to other antennae beams as a user moves about.

Another important point is that the mMIMO systems require an environment with signal interference or spatial diversity; that is a rich diversity of signal paths between the transmitter and the receiver, which is engineered through multiple original signal sources, or be caused naturally by obstacles, such as buildings and other structures, that deflect, refract or scatter a signal (See Figure 2). (Mimo is currently implemented in 4G systems to accommodate this, take, for example, 4G smartphones have 2 MIMO antennae.) Of course, if humans are caught regularly in high strength beams, this increases the risk of non-thermal effects. That will most likely occur with extremely high-frequency mmWave RFR: However, mMIMO may also be deployed at the other bands, particularly the high-frequency cmWave band.

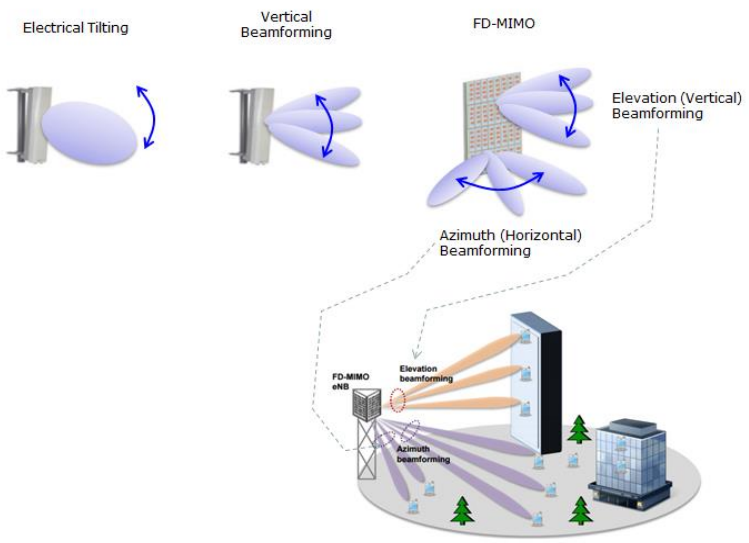

Figure 3 Beamforming in Azimuth and Elevation

While such approaches save significant energy over systems that employ wide-beam antennae, they also deliver high power to specific users (and any human caught in the beam). Figure 1 illustrates this using 1 antenna, 8, and 64 antenna deployments. Note the darker the colour the stronger the signal and exposure to RFR. The signal quality and data transfer rates are also higher. In a properly engineered solution, the beam will transmit high powered signals that would have only have been experienced quite near an RFR signal source.

One significant point concerning research on the health risks of RFR is that all existing wireless technologies—2-5G, Wifi, and Bluetooth—employ pulsed electromagnetic fields in signal transmission. Scientists identified this type of RFR as having significant physical and biological effects. The extensions and innovations around the specific technological approaches that are employed in 5G signal transmission as described above have never been tested for their physical and biological effects in humans. The ICNIRP (2020) Guidelines are deficient in this regard. Thus, extant research on 2-4G and Wifi technologies, as well as other relevant technologies form the only scientific knowledge base on which to perform a risk assessment on 5G.

User equipment: From smartphones to the Internet of Things (IoT)

Public concern on 5G is oriented towards far-field sources, such as base-station antennae. What is generally ignored is the explosion of near-field sources of 5G RFR that will effectively saturate the home, school, and work environments in high- and low-strength RFR. Of course, this is in addition to pre-existing 3-4G, Wifi, and Bluetooth sources.

If we take an existing 4G smartphone, it can transmit RFR from several sources, depending on network and user settings. In a worst-case scenario, which would be the norm for the majority of users, 4G voice and data (inc. MIMO), Wifi (2.4Ghz and 5GHz), Bluetooth, and NFC (near field communication) radio units are active. That is six sources of RFR, potentially emitting all at once. Of course, smartphones have energy-saving and sleep features that switch apps and radio units off, until required. But children, adolescents, and adult users rarely use such features as the psychological need to be connected at all times overrides energy conservation. The vast majority

of users are also unaware of the risks of non-thermal effects: these happen due to users' frequent exposures to RFR at a long duration, even at low levels.

5G smartphones may have up to 8 radio units: 3G, 4G, 5G (low (phone), high and extremely high for data), Wifi (2.4GHz and 5GHz), Bluetooth, and NFC. In 5G mode, 3 and 4 G radios will be disabled, but depending on user needs, up to seven radio units could be That's up to 5 separate signals or more, across all frequencies from 700Mhz to 28GHz. Near-field or far-field that is a lot of non-ionizing energy. Please refer to the following for 4G phone frequencies for an Apple iPhone.[6] Also see this Samsung 5G phone, which is capable of 2-5G, Wifi (2.4 & 5G), Bluetooth and NFC. Note 2-3G is available on most phones. However, in 2020 5G smartphones and a range of IoT devices also have beamforming capabilities for 28Ghz mmWave transmission. The implications here are that high-energy near-field beam formed RFR signals from these devices create significant health and safety concerns, particularly for children and adolescents. Take, for example, a 5G phone using mmWave communications when the base-station source is directly behind the user in elevation means the beam could be radiating directly into the users eyes—this could be catastrophic for a child.

In sum, adults and children face multiple RFR sources both near-field and far-field. Significantly, ICNIRP (2020) Guidelines do not capture the complexity or impact of multiple sources or all use cases. Neither do these guidelines incorporate the scientific, peer-reviewed studies that indicate clear and present dangers to people.

A summary of the known health risks of non-ionizing RFR

The overwhelming majority of published peer-reviewed scientific studies in biomedical research databases PubMed, Ovid Medline, EMBASE, Cochrane Library, and those listed in Google Scholar, indicate significant health risks with RFR of the type used in 5G technologies, both near field in the home and far-field in antennae, whether on access points or masts. This is the view of the majority of scientists across biomedical and related fields. Take for example that as of April 30, 2020, 253 EMF scientists from 44 nations have signed the EMF Scientist Appeal to the United Nations the *"WHO and UNEP, and all U.N. Member States, for greater health protection on EMF exposure."*[7] Similarly, as of May 18, 2020, 377 scientists and medical doctors signed the 5G Appeal to the EU.[8]

The majority of scientific studies also show physical and biological effects viz. *"As of the 15th September 2017, the clear majority of 2653 papers captured in the database examine outcomes in the 300 MHz–3 GHz range. There are 3 times more biological "Effect" than "No Effect" papers; nearly a third of papers provide no funding statement; industry-funded studies more often than not find "No Effect", while institutional funding commonly reveal "Effects""* (Leach et al. 2018). Simply put, as of 2017 68% of peer-reviewed scientific research studies, or the majority view, find physical and biological non-thermal effects, while only 32% of studies, the minority position, find evidence thermal effects only. That majority view % has increased since then, weakening further the perspective of no-threat to human health and well-being

It must be noted, however, that the minority view is led by a group of 13 influential scientists from the International Commission on Non-Ionizing Radiation Protection (ICNIRP). Significantly,

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[6] https://fccid.io/BCG-E3175A

[7] https://www.emfscientist.org/

[8] http://www.5gappeal.eu/signatories-to-scientists-5g-appeal/

commission members have strong links with the telecommunications industry and hold key roles in the WHO, the International Agency for Research on Cancer (IARC), and the EU's Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). Thus, the minority view dominates through political influence, not the preponderance of scientific evidence. The majority view is represented in the findings of thousands of peer-reviewed empirical studies on microwave non-ionizing RFR focusing on the biomedical effects of 2-4G and WiFi technologies (see Di Ciaula, 2018; Miligi, 2019; Russell, 2018; and Kostof et al. 2020, for examples). There are also several reviews and general studies focusing on extremely high frequencies up to 100GHz that may be used in 5G (Neufeld and Kuster, 2018; Simkó and Mattsson, 2019).

The overwhelming majority of studies conclude that there is a high risk of adverse biological effects on humans at low, high, and extremely high frequencies. Recent research funded by DARPA (US Defense Advanced Research Projects Agency) finds that ICNIRP guidelines focus on short-term risks only, not long-term exposures to weak RFR: this despite *"a large and growing amount of evidence indicates that long-term exposure to weak fields can affect biological systems and might have effects on human health" with significant "public health issues""* (Barnes and Greenebaum, 2020. p. 1). Furthermore, research also finds biological effects at high frequencies may add to and compound those predicted at lower frequencies (Kostoff et al., 2020).

A recent research review on the health risks of RFR, involving independent verification based on 5,400 studies in the MedLine database, concludes that "*the literature shows there is much valid reason for concern about potential adverse health effects from both 4G and 5G technology"* and that extant research *"should be viewed as extremely conservative, substantially underestimating the adverse impacts of this new technology"* (Kostoff et al. 2020).

Kostoff et al. report that peer-reviewed studies show the following adverse health effects well below the safety limits set by the UK based on ICNIRP guidelines:

- *"carcinogenicity (brain tumors/glioma, breast cancer, acoustic neuromas, leukemia, parotid gland tumors),*
- *genotoxicity (DNA damage, DNA repair inhibition, chromatin structure), mutagenicity, teratogenicity,*
- *neurodegenerative diseases (Alzheimer's Disease, Amyotrophic Lateral Sclerosis),*
- *neurobehavioral problems, autism, reproductive problems, pregnancy outcomes, excessive reactive oxygen species/oxidative stress, inflammation, apoptosis, blood-brain barrier disruption, pineal gland/melatonin production, sleep disturbance, headache, irritability, fatigue, concentration difficulties, depression, dizziness, tinnitus, burning and flushed skin, digestive disturbance, tremor, cardiac irregularities,*
- *adverse impacts on the neural, circulatory, immune, endocrine, and skeletal systems."*

Another recent systematic review focusing on assessing the risks and health effects of WiFi RFR is relevant, as it provides the nearest analogue to 5G RFR sources due to the fact that WiFi applies similar transmission techniques (OFDM, MIMO, beamforming etc.) and because of WIFi's general ubiquity in private and public spaces such as homes, libraries, hospitals, hotels, shopping malls, and all public transport. 100 *in vitro* and *in vivo* research studies were selected from peer-reviewed journals in ZBMED and PubMed. The review found that and almost all studies demonstrated physical, biological and/or behavioural effects at RFR signal levels below the ICNIRP safety guidelines. Effects were demonstrated on the reproductive system, EEG and brain functions, as well as effects on learning, memory, attention, and behavior, and also physical effects on the heart, liver thyroid, gene expression, cell cycle, and cell membranes of animal subjects (Wilke, 2018). The majority of studies identified oxidative stress as the operative mechanism. The research concluded that *"Current exposure limits and SAR values do not protect*

from health risks associated with Wi-Fi radiation. The adverse effects on learning, attention, and behavior serve as a basis for educational institutions of all age groups to forgo the use of Wi-Fi applications. Due to cytotoxic effects, Wi-Fi technologies are not suitable for hospitals and telemedicine." (ibid.).

What is the significance of the U.S. NTP and Ramazzini Institute studies?

The recent study by the National Toxicology Program's (NTP) at the U.S. Department of Health and Human Services is the point of departure for this paper's review of the scientific research on mobile and wireless RFR from all sources.

In 1999, the US Food and Drug Administration's (FDA) Center for Devices and Radiological Health commissioned the National Toxicology Program study on the potential toxicity and carcinogenicity of RFR (FDA, 1999). The FDA's concerns followed the emergence and widespread use of first generation cell phone devices in the early 1980s and second generation (2G) systems in the 1990s. The health focus and associated safety standards were, and still are, centred on the thermal effects (i.e. heating of tissues from microwaves) and not on the non-thermal effects. The EPA (McGaughy et al., 1990) study aside, there was doubt as to the potential negative health implications of low-intensity RFR, especially where cancer was concerned (Vijayalaxmi and Obe 2004). Hence, the FDA wished to bring clarity to reassure the US public and requested the NTP to investigate whether RFR exposures could cause cancer.

On November 1st 2018, the final report of a 10-year $30m comprehensive study by US National Institute of Environmental Health Sciences' National Toxicology Program (NTP) confirmed that radio frequency radiation (RFR) from 2G and 3G cell phones caused cancer in animals (National Toxicology Programme, 2018a). That study clearly refutes the long-held theory that non-ionizing radiation, such as RFR, cannot cause cancers or lead to other effects on the health and well-being of humans (National Toxicology Programme, 2018b).

The findings of this study create immense problems for mobile phone companies and BigTechs such as Apple, Facebook, Google, and others, as the use of microwave RFR technologies underpin their business models. Furthermore, the NTP adds *"5G is currently emerging and will eventually overtake the existing 2G, 3G, and 4G technology. In the meantime, consumers will continue to be exposed to RFR from these sources in the 700-2700 MHz range. As the 5G network is implemented, some of the signals will use the same lower frequencies as the older technology previously studied by NTP. Additionally, concern has been raised because the 5G network will also use higher frequencies, up to 60,000 MHz, thereby exposing wireless consumers to a much broader spectrum of frequencies. The higher frequencies, known as millimeter waves, can rapidly transmit enormous amounts of data with increased network capacity compared to current technologies…NTP is currently evaluating the existing literature on the higher frequencies intended for use in the 5G network and is working to better understand the biological basis for the cancer findings reported in earlier studies on RFR with 2G and 3G technologies."*

In the press release accompanying the NTP Final Report, Dr. John Bucher, Senior Scientist, at the National Toxicology Program *stated, "We have concluded that there was clear evidence that male rats developed cancerous heart tumors called malignant schwannomas. The occurrence of malignant schwannomas in the hearts of male rats is the strongest cancer finding in our study"* (National Toxicology Programme, 2018c). Categorising the major findings as *"clear evidence"* is significant as this is the highest burden of proof in a scientific study by the NTP. It employs 4 levels of evidence. Other findings were categorised as *Some Evidence* (brain tumours such as glioma and adrenal gland tumours) and *Equivocal* (cancers of the prostate and pituitary glands).

None of the findings were at level 4, No Evidence. The paper discusses these findings in the context of previous research.

The NTP study was not the first of its kind—it confirms the findings of previous research on the links between near field RFR exposure and various cancers—it is the most comprehensive, however. Since 1990 when the EPA flagged the issue of potential non-thermal carcinogenic effects of microwave RFR, a wealth of experimental and epidemiological research demonstrated the very real biological effects of RFR on the brain, nervous systems, hearts, and testes of mammals, including humans. Cancers aside, many of these studies consistently report a range of side-effects in humans, from sleep deprivation and headaches, to neurological damage, and learning disorders (Glaser, 1976; Belpomme et al., 2018). The NTP study also reported that DNA damage (strand breaks) was significantly increased in the brains of rats and mice exposed to RFR. The findings also reported reduced birth weights of rat pups whose mothers were exposed to RFR, in addition to cardiomyopathy of the right ventricle in the rats studied (Wyde, 2016; Wyde et al., 2018).

Dr. Fiorella Belpoggi, Director of the Cesare Maltoni Cancer Research Center of the Ramazzini Institute, which had recently conducted separate research that echoed the findings of the NTP Study, took issue with the ICNIRP—*"We are scientists, our role is to produce solid evidence for hazard and risk assessment. Underestimating the evidence from carcinogen bioassays and delays in regulation have already proven many times to have severe consequences, as in the case of asbestos, smoking and vinyl chloride."*[9]

In the Ramazzini Institute study, Dr Belpoggi's colleagues Falcioni et al. presented their *"findings on far field exposure to RFR [that] are consistent with and reinforce the results of the NTP study on near field exposure, as both reported an increase in the incidence of tumors of the brain and heart in RFR-exposed Sprague-Dawley rats. These tumors are of the same histotype of those observed in some epidemiological studies on cell phone users. These experimental studies provide sufficient evidence to call for the re-evaluation of IARC conclusions regarding the carcinogenic potential of RFR in humans"* (Falcioni et al., 2018). Again, to emphasize, this study is notable as it focused on the health implications of far-field RFR sources on humans living or working in the proximity of mobile phone base stations, as opposed to operating 2 & 3 G handsets near field. It is also the largest long-term study ever performed in rats on the health effects of RFR. Its findings are therefore of particular concern for those, particularly children, living near RFR sources, such as mobile phone masts or WiFi routers. The ICNIRP decided that the findings did not provide a reason to revise current (i.e. over 21-year-old) RFR exposure standards. However, Dr. Ronald Melnick rebutted the ICNIRP analysis stating it contained several false and misleading statements (Melnick, 2019, 2020).

What is proof of the potential toxicity and carcinogenicity of RFR?

In 2011 the IARC classified WiFi and microwave radiation from cordless and mobile phones as a ***possible*** Class 2B carcinogen. While the findings of epidemiological studies have been debated, and chiefly focus on the long-term development of brain tumours, a recent review of such studies is unequivocal and states that *"[m]obile phone radiation causes brain tumors and should be classified as a **probable** human carcinogen (2A)"* by the WHO's International Agency for Research on Cancer (IARC) (Morgan et al. 2015). However, the evidence presented herein led scientists to conclude that it should be reclassified (IARC Monographs Priorities Group, 2019),

[9] https://www.ramazzini.org/comunicato/onde-elettromagnetiche-listituto-ramazzini-risponde-allicnirp/

with strong arguments being put forward from a variety of scientists for RFR to be a Class 1 human carcinogen (Miller et al., 2018).

Following the release of the NTP peer-review study, Belpomme et al. (2018) pointed out that *"[t]he classification of RF-EMFs as a "possible" human carcinogen was based primarily on evidence that long-term users of mobile phones held to the head resulted in an elevated risk of developing brain cancer. One major reason that the rating was not at "probable" or "known" was the lack of clear evidence from animal studies for exposure leading to cancer."* The NTP studies now mean that this obstacle to RFR reclassification as a probable or know Class 1 carcinogen is only a matter of time. In his critical review of both the above studies, former ICNIRP commissioner James Lin (2019, p. 19) concluded that: *"The time is right for the IARC to upgrade its previous epidemiology based classification of RF exposure to higher levels in terms of the carcinogenicity of RF radiation for humans."* This is clear and unambiguous as the findings of both the NTP and Ramazzini Institute studies that provided *"clear evidence,"* the highest burden of scientific proof possible concerning the carcinogenicity of RFR (Melnick, 2019).

The IARC Monographs Priorities Group (2019) publication specifically points to the NTP (2018a,b) and Ramazzini Institute studies (Falcioni et al., 2018) to highlight advances in animal studies. It also points to research by Kocaman et al. (2018) which concludes that *"Results from in vitro and in vivo studies represent strong evidence of a carcinogenic effect of RF, but epidemiological studies have not yet confirmed this."* Nevertheless, scientists from the IARC Monograph Priority Group did find the following studies compelling: Coureau et al. (2014); Carlberg & Hardell (2015); Pedersen et al. (2017). Note these epidemiological studies were not considered by Kocaman et al. (2019).

Take for example that Pedersen et al. (ibid.). *"observed elevated risks of dementia, motor neurone disease, multiple sclerosis and epilepsy and lower risks of Parkinson disease in relation to exposure to ELF-MF in a large cohort of utility employees."* Both the Coureau et al. and Carlberg and Hardell studies noted the *"possible association between heavy mobile phone use and brain tumours"* Coureau et al., 2014). However, the long latency in the development of such tumours and the time periods of exposure mean that further epidemiological studies are required. The IARC Monograph Priority Group concluded in its *"**Recommendation for non-ionizing radiation (radiofrequency):** High priority."*

A bibliography of epidemiological research and reviews on cancers in humans since the IARC RFR classification in 2011 is presented in Appendix A. This lists 60 studies, 57 of which did not inform the deliberations of IARC Monograph Priority Group. The studies listed include those which demonstrate general trends in the increase in the incidence of cancers of the CNS and other human systems, as well as studies that examine the relationship between RFR exposure and the subsequent development of cancer. The following categorizations were employed with a small number of studies indicating more than one link.

- Brain tumors [1-26]
- Tumors of the Meninges (Meningioma) [27-32]
- Hearing Nerve Tumor (vestibular Schwannoma; acoustic neuroma) [33-37]
- Parotid Gland Cancer [38-42]
- Eye Cancer [43-47]
- Cancers of the Breast (male and female) [48-52]
- Melanoma of the Skin [53-54]
- Leukemia [55-57]
- Thyroid Cancer (male and female) [58-62]
- Colorectal Cancers [62-65]

- Multiple Cancers [66-72]

Subsequent sections explore the findings of key studies in this bibliography. However, at this juncture, it is important to note the increase in epidemiological evidence and the urgent need for further research in this area before the wide-scale deployment of 5G. The need for this will become apparent in the following.

What is the evidence from epidemiological studies?

After more than 25 years of widespread cell phone use, one would expect to see a rise in cancers, particularly brain tumours. The evidence here is mounting: Take for example new studies in the US note a disturbing rise in cancers of the Central Nervous System, particularly in adolescents. There is also a marked increase in other cancers. Nevertheless, while recent research has provided *"clear evidence"* of a link between RFR and cancers in laboratory animals, epidemiological studies have yet to provide conclusive evidence of an increase in the incidence, prevalence, and mortality rates in humans of cancers directly linked with RFR from 2-4G, Wifi, and wireless devices.

There are several reasons for this: One of the chief explanations is the fact that it typically takes between 20 or 30 years for many types of cancers to develop following exposure to a carcinogen, and for epidemiological data to reflect this and to enable risk assessment. Besides, it must be noted that well-designed studies *"require populations that are followed for at least 20 years, preferably 30 or more"* (Michaels, 2008, p. 82). That has not been the case with extant or industry-sponsored studies (cf. Belpomme et al., 2018): Thus, the findings and conclusions drawn from *"observations [of such studies] may be premature, as cell phone use has become commonplace only within the past two decades, a period of time that may be insufficient to accurately assess cancer-related outcomes"* (Smith-Roe et al., 2020, p. 277).

CNS cancers

In 2019 two social scientists reported *"that mobile phone subscription rates are positively and statistically significantly associated with death rates from brain cancer 15-20 years later. As a falsification test, we find few positive associations between mobile phone subscription rates and deaths from rectal, pancreatic, stomach, breast or lung cancer or ischemic heart disease"* (Mialon and Nesson, 2019). This 25-year cross country analysis provides solid but indirect evidence of the link between mobile phone use and cancer. The study supports what epidemiologists examining the relationship between exposure to mobile phone RFR and cancer have been finding. However, a closer look at the available evidence is required to understand probability and causality.

Recently, The Lancet Neurology observed that *"CNS cancer is responsible for substantial morbidity and mortality worldwide, and the incidence increased between 1990 and 2016"* (Patel et al., 2019). This is just one of several recent epidemiological studies that note such increases (see Ostrom et al., 2016: Khanna et al., 2017; Withrow et al., 2018, for others).

A comprehensive review of the incidence of primary brain and other central nervous system tumors diagnosed in the United States during the period 2009–2013, found quite small, but statistically significant increases in some categories of CNS tumours and none in others (Ostrom et al. 2016). A related U.S. study echoed the US findings but found *"an increasing medulloblastoma incidence in children aged 10–14 years"* (Khanna et al., 2017). A recent study on children found statistically-significant changes in several sub-types of CNS cancers, notably gliomas, in the period 1998-2013 (Withrow et al., 2018). The latter study concluded that

"Continued surveillance of pediatric CNS tumors should remain a priority given their significant contribution to pediatric cancer deaths."

In a general context, the U.S. Center for Disease Control and related research finds that non-Hodgkin lymphomas, central nervous system tumors (including brain cancers), renal, hepatic and thyroid tumours have increased recently among adolescent Americans (Siegel et al., 2018; Ostrom et al., 2018). When comparing the Annual Average Total and Average Annual Age-Adjusted Incidence Rates for Children and Adolescents of Brain and Other Central Nervous System Tumors from 2009-2013 (Ostrom et al., 2016) and 2012-2016 (Ostrom et al., 2018) an increase in total cases of 0-19 year olds from 23,522 to 24,931 is found, with the annual average increasing from a rate of 5.70 in 2012 to 6.06 to 2016. Thus, many scientists conclude that microwave radio frequency radiation has a significant role to play in the increasing rates of particular types of CNS cancers being reported.

In examining the risk factors for brain tumours, Ostrom et al. (2019) state that *"Primary brain tumors account for ~1% of new cancer cases and ~2% of cancer deaths in the United States; however, they are the most commonly occurring solid tumors in children. These tumors are very heterogeneous and can be broadly classified into malignant and benign (or non-malignant), and specific histologies vary in frequency by age, sex, and race/ethnicity. Epidemiological studies have explored numerous potential risk factors, and thus far the only validated associations for brain tumors are ionizing radiation (which increases risk in both adults and children) and history of allergies… While identifying risk factors for these tumors is difficult due to their rarity, many existing datasets can be leveraged for future discoveries in multi-institutional collaborations."* While ionizing radiation is a clear causal factor, scientists have concluded there is strong evidence that non-ionzing RFR is the environmental factor responsible for current increases. Indeed, the Turin Court of Appeal came to the same conclusion in 2019.[10]

The most common of all central nervous system (CNS) tumors are gliomas, with the most common of these being the high grade glioblastoma multiforme, which has a survival time of less than one year (Ohgaki and Kleihues, 2005). A research review of the incidence of glioblastoma multiforme tumours in England during 1995–2015 reported *"a sustained and highly statistically significant ASR [(incidence rate)] rise in glioblastoma multiforme (GBM) across all ages. The ASR for GBM more than doubled from 2.4 to 5.0, with annual case numbers rising from 983 to 2531. Overall, this rise is mostly hidden in the overall data by a reduced incidence of lower-grade tumours."* (Philips et al., 2018). The study did not focus on RFR as the cause, so the findings must be considered 'open to interpretation' in this regard, as other environmental mechanisms cannot be ruled out. However, the following figures are clear and unambiguous. In the UK in 1995, 553 frontal lobe tumours were diagnosed in patients, while 1231 were found in 2015. Likewise, 334 temporal lobe tumours were reported in 1995, while 994 were diagnosed in 2015. The increase in these cancers of the CNS are clear and unambiguous. The authors of this study argue that:

> *"The rise cannot be fully accounted for by promotion of lower–grade tumours, random chance or improvement in diagnostic techniques as it affects specific areas of the brain and only one type of brain tumour. Despite the large variation in case numbers by age, the percentage rise is similar across the age groups, which suggests widespread*

[10] https://www.diritto24.ilsole24ore.com/_Allegati/Free/Ca_torino_vers_1.pdf

environmental or lifestyle factors may be responsible. This article reports incidence data trends and does not provide additional evidence for the role of any particular risk factor."

Significantly, the frontal and temporal lobes receive the greatest exposure to RFR from smartphones and tablets.

Another recently discovered mechanism found to affect the growth of glioblastoma multiforme tumours in humans is the p53 protein (Akhavan-Sigari et al.,2014). Glioblastoma is the most common and most malignant of the glial tumours found in the brain and central nervous system (Philips et al., 2018). Akhavan-Sigari et al. studied 63 patients with this type of tumour and found that patients that used *"mobile phones for ≥3 hours a day show a consistent pattern of increased risk for the mutant type of p53 gene expression in the peripheral zone of the glioblastoma, and that this increase was significantly correlated with shorter overall survival time."* This is a significant finding.

More worrying is a recent study conducted on the Swedish National Inpatient Register: *"The main finding in this study was increasing rate of brain tumor of unknown type in the central nervous system"* (Hardell and Carlberg, 2015a). The research being conducted by the 'Hardell Group' in Sweden, which is responsible for this study, has consistently demonstrated a link between mobile phone use and cancer. Two recent studies from the group confirm the link between RFR and cancers in humans. In the first, both mobile and cordless phones were associated with an increased risk of glioma, a type of brain tumour (Hardell and Carlberg, 2015b). It found that the *"First use of mobile or cordless phone before the age of 20 gave higher OR [odds ratio] for glioma than in later age groups."* This indicates that children or teenagers are at significant risk. In the second, researchers found that the rise in thyroid cancers in Sweden was linked with an increase in exposure to RFR (Carlberg et al., 2016). To be sure, epidemiological studies such as the latter are akin to looking for a needle in a haystack and are criticised by some as being flawed, however, their findings need to be viewed in a new light given the scientific evidence emerging from laboratory experiments such as the NTP study, as indicated below.

Three research groups researched the links between mobile and wireless phone use and brain tumours: These case-control studies on glioma were performed by Interphone, (2010); CERENAT (Coureau et al., 2014); Hardell Group (e.g. Hardell and Carlberg, 2015; Carlberg and Hardell, 2017). The French CERENAT study reported that *"Consistent with previous studies, we found an increased risk [of brain tumours] in the heaviest users [of mobile phones], especially for gliomas."* (Coureau et al., 2014). The study found the risks were higher for temporal lobe tumours, as well as gliomas, with occupational and urban mobile phone users at the highest risk.

Applying the Bradford Hill Guidelines to epidemiological research on brain cancers

Carlberg and Hardell (2017) apply the Bradford Hill Guidelines to assess all three studies and concludes that in terms of the ***Strength*** of the relationship that there is a *"statistically significant increased risk for glioma."* In terms of ***Consistency***, they found that "*similar results should be found by different research groups and in different populations*." In terms of ***Specificity,*** "*the association between RF radiation and brain tumour risk was specific for glioma."* ***Temporality****:* exposure to RFR and tumour development is important, hence the findings that "latency and ipsilateral mobile phone use show that there was an increased OR with short latency and after some decline an increasing risk with longer latency. In terms of ***Biological Gradient*** or dose-response, the *"highest risk [was found] in the highest group of cumulative use."* Considering, ***Plausibility***, it addresses the biological plausibility of a disease. In their review, they note the NTP findings and state in 2017 that these *"results have gained considerable interest since epidemiological human studies have in addition to glioma also found an increased risk for acoustic*

neuroma, also called vestibular schwannoma." Carlberg and Hardell (2017) point to the role of oxidative stress and the *"concomitant increase in reactive oxygen species (ROS)"* in studies, and that *"these results on oxidative stress are of concern since ROS are of crucial importance in carcinogenesis."* As other studies cited herein indicate, ***Plausibility*** is no longer in question. ***Coherence*** concerns exposure to RFR would *"change the biology and natural history of the disease"* thereby strengthening an association. The authors report that in a study by Akhavan-Sigari et al. (2014) *"it was found that use of mobile phones for ≥3 hours a day was associated with increased risk for the mutant type of p53 gene expression in the peripheral zone of glioblastoma multiforme, the most malignant glioma type. Furthermore, this mutation increase was statistically significant correlated with shorter overall survival time."* Using this and other findings the ***Coherence*** requirement was met. ***Experiment*** concerns the use of preventative measures to reduce risk. In the case of RFR from mobile phones, users who use hands-free or car phones with external aerials should in theory have lower incidence of disease. This was found to be the case. Also discussed was the role of antioxidants *"such as melatonin, vitamin C, and vitamin E (α-tocopherol) [that] may alleviate the generation of ROS…There are however no studies of persons taking antioxidants and using wireless phones have a reduced risk for glioma."* The final viewpoint is ***Analogy***: *"Is there some evidence* [of disease] *with another similar exposure?"* They propose that *"One analogy would be glioma risk associated with extremely low frequency electromagnetic fields (ELF-EMF)"…*another IARC Class 2B Carcinogen. Carlberg and Hardell (2017) demonstrate how EFF-EMF is linked with *"increased risk in late stage (promotion/ progression) of glioblastoma multiforme for occupational ELF-EMF exposure."*

Prasad et al. (2017) *"found evidence linking mobile phone use and risk of brain tumours especially in long-term users (C10 years). Studies with higher quality showed a trend towards high risk of brain tumour, while lower quality showed a trend towards lower risk/protection."* In addition, extensive studies by the Hardell Group demonstrate increases in cancers of the CNS in Sweden (Hardell and Carlberg, 2015a,b, 2017). These findings have been recently replicated in Denmark (Swedish Radiation Protection Foundation, 2017).

In keeping with studies that provide compelling evidence for concern, a recent review of epidemiological studies on brain and salivary gland tumours concerning mobile phone use found the inconclusive evidence but indicated that such cancers may have a long latency (i.e. greater than 15 years) and clear evidence may emerge in the future. Nevertheless, scientists argue that childhood use of RFR devices is of significant concern (Röösli et al. 2019). In contrast, a separate and more recent review found that *"[e]pidemiological studies noticed a causal association between the exposure to RF-EMF and the incidence of brain neoplasm in different populations since this is the organ with the highest specific absorption rate. The fact that so many of the ipsilateral tumors found are statistically significant with RF-EMF exposure provides weight suggesting causality. In this way, the higher the exposure (ipsilateral vs contralateral), the longer the cumulative exposure (hours of exposure) and the longer the latency (beyond 10 years); the greater the risk. In addition, considering together all of these parameters suggest a strong causality"* (Pareja-Peña et al., 2020).

Evidence on an uptick colorectal cancer

We have all witnessed how adolescents and young adults predominantly carry their smartphones in trouser pockets. If the theory that RFR causes cancer is correct then we should see an uptick in local cancers in that region of the body as the radio units in smartphones are active, even in standby. In 2019, the journal *Cancer* described a rising incidence of colorectal cancer among young Americans, with rectal cancers being slightly higher than colon cancers (Virostko et al., 2019). Another contemporary study found significant increases in colorectal cancer among

people under 50 in Denmark, New Zealand, and the UK since 2009 (Araghi et al., 2019). Yet another study of colorectal cancer in young adults in 20 European countries over the last 25 years found that over the last 10 years, the incidence of colorectal cancer increased 8% per year among people in their 20s, by 5% for people in their 30s, and by 1.6% for those in their 40s (Vuik et al., 2019). Dr. De-Kun Li [11] maintains that *"When placed in trouser pockets, the phones are in the vicinity of the rectum and the distal colon and these are the sites of the largest increases in cancer."* He concludes that there is a link between how people carry, as well as use, their phones, and the rising incidences of various cancers and other health risks. For example, researchers found that RFR from cell phones may be triggering breast cancer in young women who carry their devices on or near their breasts (West et al., 2013)

Implications for skin cancers

5G systems present a perfect storm where the above health risks are concerned. Not only will they expose adults and children to near- and far-field 3-5G RFR signals, but 5G technologies also expose them with low frequency, high frequency, and extremely high frequency RFR simultaneously. The aforementioned health risks are linked with: Low frequency 5G RFR which penetrates deep into the body; high frequency, which penetrates sufficiently deep to be of significant concern, permeating as it does the brain; and extremely high frequency, which chiefly affects the skin and eyes. Scientists at the ICNIRP have questionable competencies to deal with this from a biomedical perspective, as they dismiss any significant thermal or non-thermal risks in light of the cumulative body of evidence.

Extremely high-frequency RFR penetrates and is absorbed into the skin, i.e. epidermis, dermis, and subcutaneous fat, and also into the eyes (Feldman et al., 2009). Research on the biological effects of extremely high-frequency RFR is mature (Zalyubovskaya, 1977). There are, therefore, significant concerns about the biological effects of this type of RFR in relation to their use in 5G (Di Ciaula, 2018). In medical and scientific terms the skin does not form a barrier to extremely high-frequency RFR, it is permeable. It is a biological organ that protects the body but is itself prone to infections and environmental influence. It contains capillaries and nerve endings and is both an input and output from the CNS (Duck, 1990). It is in medical terms a vital organ. Significantly, therefore, researchers point out that *"More than 90% of the transmitted power [of extremely high frequency RFR] is absorbed by the skin"* (Zhadobov et al., 2011). This is significant, as this energy is not harmlessly dissipated. Consequently, with regular exposure skin cells go into oxidative stress with significant health implications and risks (Neufeld and Kuster, 2018).

Furthermore, it is also important to note that *"the cumulative body of research and scientific evidence demonstrates beyond a reasonable doubt that [extremely high-frequency RFR] not only penetrate the skin of humans but present a heightened risk of ill-effects on all biological systems including cells, bacteria, yeast, animals and humans"* (Zhadobov et al., 2011). This evidence refutes the ICNIRP assertion that 5G RFR produces thermal effects only. The implications of ubiquitous extremely high-frequency RFR illustrate this point. Research on ultraviolet radiation indicates that UVB is ionizing radiation and directly damages DNA, which may lead to melanoma. UVA, on the other hand, is non-ionizing. Both are on the electromagnetic spectrum along with non-ionizing RFR. UVA, which accounts for 95% of incident UV radiation, causes oxidative DNA damage through the way in which it creates reactive oxygen species (ROS) (Brem et al., 2017).

[11] De-Kun Li, MD, PhD, MPH, is a Senior Research Scientist at the Division of Research, Kaiser Permanente Northern California. https://microwavenews.com/news-center/de-kun-li-crc

"DNA damage caused by UVA-induced ROS is a potential contributor to sun-induced mutation and cancer" (McAdam, Brem, and Karran, 2016, p. 612). Scientists acknowledge that *"the growing incidence of melanoma is a serious public health issue…[and] UVA-associated DNA damage responses may contribute to melanoma development"* (Khan, Travers, and Kemp, 2018). Any exogenous agent that increases ROS can either directly or indirectly cause skin cancers such as melanoma. Research has demonstrated unequivocally that RFR increases ROS and decreases vital anti-oxidants. Thus, it is axiomatic that extremely high-frequency RFR poses a significant threat to human health as people are increasingly vulnerable to skin cancers—both melanoma and non-melanoma.

Evidence on the promotion of existing cancers and susceptibility

One important recent finding is that RFR has cocarcinogenic effects. In research published in 2010, carcinogen-treated mice exposed to RFR demonstrated significant tumour-promoting effects (Tillmann et al., 2010). A study by Lerchl et al. replicated the earlier study using higher numbers of animals in both the control and experimental groups (Lerchl et al., 2015). That study confirmed and extended the previous findings. They report that the numbers of tumours of the lungs and livers of exposed animals were significantly higher than in the control groups. They also reported significantly elevated lymphomas through RFR exposure. The scientists hypothesized that cocarcinogenic effects may have been *"caused by metabolic changes due to exposure."* It is significant, and extremely worrying, that tumour-promoting effects were produced *"at low to moderate exposure levels (0.04 and 0.4 W/kg SAR), thus well below exposure limits for the users of mobile phones."* The authors conclude that their *"findings may help to understand the repeatedly reported increased incidences of brain tumors in heavy users of mobile phones."* The mechanisms presented in the previous section help explain why and how RFR exposures induce the observed findings in these and other studies.

Links with miscarriage and risks to the fetus and early childhood development

A prospective cohort study of 913 pregnant women conducted by Dr. De-Kun Li and his team at US healthcare provider Kaiser Permanente examined the association between exposure to non-ionizing radiation from low-frequency EMF sources and the risk of miscarriage (Li et al., 2017). After controlling for multiple other factors, women who were exposed to higher levels had 2.72 times the risk of miscarriage (hazard ratio = 2.72, 95% CI: 1.42–5.19) than those with lower exposures. The increased risk of miscarriage was consistently observed regardless of the EMF sources (Li et al., 2017). However, follow-up studies on children born to mothers with the same high levels of exposure found that in-utero exposure was related to an increased risk in children of the following conditions:

- Asthma 2.7 times;
- Obesity 5 times;
- ADHD 2.9 times. (Li et al. 2011, 2012)

Li et al. (2017) link the results from this study with contemporary epidemiological research on the links between far-field exposure to RFR from mobile phone antennae and miscarriage (Zhou et al. 2017) and near-field exposure linked with mobile phone use during pregnancy (Mahmoudabadi et al., 2017).

Research conducted at Professor Hugh Taylor's research laboratory at Yale comments on the significant increase in the incidence of ADHD in children. Taylor and his team posit that one or

more environmental factors are involved. The paper showed that pre-natal in-utero exposure of pregnant mice to real cell phone RFR produced three highly statistically significant changes observed in mice exposed in-utero. These are: (1) a decrease in memory function; (2) hyperactivity; and (3) an increase in anxiety. The researchers *conclude "that these behavioral changes were due to altered neuronal developmental programming"* (Aldad et al., 2012: cf. Ikinci, et al., 2013; Zhang, 2015). These results have been replicated in several subsequent experimental studies on rodents (Othman et al., 2017a,b; Kumari et al., 2017). However, there are also several epidemiological studies that identify similar outcomes in children (Divan et al., 2008, 2012). More recently, Birks et al. (2017) used data from studies in five different countries involving 83,884 children which concluded that mobile phone use by mothers during pregnancy increased the risk of hyperactivity and attention issues with children.

This body of research provides evidence for an association between prenatal exposure to cell phone RFR and neurological development as well as the risk of spontaneous abortion. This should stimulate a reassessment of the risks concerning all EMF and RFR exposure, particularly to children and pregnant women, as *"[t]he level of proof required to justify action for health protection should be less than that required to constitute causality as a scientific principle"* (Frentzel-Beyme, 1994). We are far beyond that level of proof where RFR is concerned.

What are the implications for childhood RFR exposure?

All this has profound implications for the increasing numbers of children and adolescents exposed to RFR daily. And the risks to children are considerable: *"Because cells are rapidly dividing and organ systems are developing during childhood and adolescence, exposure to carcinogens during these early life stages is a major risk factor for cancer later in life. Because young people have many expected years of life, the clinical manifestations of cancers caused by carcinogens have more time in which to develop during characteristically long latency periods."* (Carpenter and Bushkin-Bedient, 2013). A recent study demonstrated that in a child's brain the hippocampus and hypothalamus absorb 1.6–3.1 times the microwave energy of an adult brain. The absorption rate is 2.5 times higher than an adult's where a child's cerebellum is concerned. The same study found that the bone marrow in a child's skull absorbs microwave radiation at a level 10 times greater than that of an adult Christ et al., 2010). Also, a child's eyes absorb higher levels of microwave radiation than adults (Keshvari, J., Keshvari, and Lang, 2006). If, as the latest scientific evidence indicates, low-level microwave radiation poses a health risk, and if safety standards are outdated, then it is logical to assume that children are at significant risk from any device radiating microwave radiation (Gandhi et al., 2012). Scientific experiments have also demonstrated that exposure to RFR and WiFi sources also affects brain development in young rats and their ability to learn and engage in routine problem solving (Ikinci et al., 2013; Narayanan et al., 2015; Wilke, 2018). The implications for brain development in children are clear, as are the consequences for their immediate well-being.

Reproductive risks from RFR exposures

The increased exposure to RFR from smartphones, WiFi, and Bluetooth is increasingly linked with risks to human fertility (Houston et al., 2016; Belpomme et al., 2018) as evidenced in the findings of epidemiological research (Rolland et al., 2013). The habit of carrying smartphones in trouser pockets has been shown to lower sperm quantity and quality (Adams et al., 2014; Rago et al., 2013). In their review of extant studies Adams et al. *"conclude that pooled results from in vitro and in vivo studies suggest that mobile phone exposure negatively affects sperm quality."* Similarly, Heuston et al. (2016) find that *"Among a total of 27 studies investigating the effects*

of RF-EMR on the male reproductive system, negative consequences of exposure were reported in 21. Within these 21 studies, 11 of the 15 that investigated sperm motility reported significant declines, 7 of 7 that measured the production of reactive oxygen species (ROS) documented elevated levels and 4 of 5 studies that probed for DNA damage highlighted increased damage due to RF-EMR exposure. Associated with this, RF-EMR treatment reduced the antioxidant levels in 6 of 6 studies that discussed this phenomenon, whereas consequences of RF-EMR were successfully ameliorated with the supplementation of antioxidants in all 3 studies that carried out these experiments." Another review determined that *"it is clear that radiofrequency electromagnetic fields (RF-EMF) have deleterious effects on sperm parameters (like sperm count, morphology, motility), affect the role of kinases in cellular metabolism and the endocrine system, and produces genotoxicity, genomic instability and oxidative stress ...The study concludes that the RF-EMF may induce oxidative stress with an increased level of reactive oxygen species, which may lead to infertility"* (Kesari et al., 2018). It is clear from Miller et al.'s (2019) analysis, and research cited above, that near-field sources of RFR pose a real threat to male and also potentially female fertility and reproduction at levels deemed safe by ICNIRP, the FCC, and PHE.

Neurological and neurodegenerative risks from RFR

The research cited above indicates significant risk to the neurological development of children in utero from EMF and RFR. There are numerous studies on the abnormal behaviour and learning of mice and rats exposed to RFR. A recent research review investigated the mechanisms by which RFR causes neurophysiological and behavioral dysfunctions (Sharma et al., 2017). The review indicated that it impairs cognitive and memory functions. The impact and severity of effects identified are linked to the duration of exposure, and level of exposure. Other recent research includes a study by Deshmukh et al. (2015), who examined the effects of chronic, low-level RFR exposure on learning capacity and memory. The researchers observed that spatial orientation, as well as learning and memory, were impaired. Another recent study, Hassanshahi et al. (2017) divided 80 male rats into control and experimental groups and exposed them to Wifi signals 12 hours a day. The researchers observed that the experimental rats displayed impaired cognitive performance.

Dr. Henry Lai (2018) reviewed summarized research from 2007-2017 on the neurobiological effects of RFR. Lai reports deficits in short-term memory in human subjects exposed to RFR, with one study reporting significant changes in cognitive functions in adolescents impoverishing the accuracy of their working memory. While these studies focused on the effects near-field RFR, a study by Meo et al. (2019) reported that high-level far-field RFR negatively affected the fine and gross motor skills, spatial working memory, and attention of exposed school-going adolescents, compared to those exposed to very weak levels of RFR. Thus, near-field and far-field RFR poses significant risks to children's neurobiological health (Markov, 2018; Elhence, Chamola, and Guizani, 2020). This is underpinned by a significant cumulative body of research in Russia, with one longitudinal study from 2006 to 2017 indicating the risks that RFR sources present to children (Grigoriev and Khorseva, 2018). These researchers found that chronic exposure to RFR may negatively affect the central nervous systems of the children.

Electrohypersensitivity (EHS) is a medically recognised condition that affects people who have developed an intolerance to EMFs. EHS describes a clinical condition first coined by experts for the European Commission (Bergqvist and Vogel, 1997). The relationship of EHS with RFR was identified in Sweden with research indicating a relatively high incidence among those living near mobile phone base stations (Santini et al., 2003). The global increase in people reporting EHS, prompted the WHO to organise an international workshop in Prague: The Prague working group

report clearly defined EHS as *"a phenomenon where individuals experience adverse health effects while using or being in the vicinity of devices emanating electric, magnetic or electromagnetic fields"* (Belpomme et al. 2018). Subsequently, the WHO acknowledged EHS as an adverse health condition (WHO, 2005). Research reveals that it remains on the increase, with occurrences having a strong link with oxidative stress. For example in one study *"80% of EHS patients presented with an increase in oxidative/nitrosative stress-related biomarkers"* (Belpomme and Irigaray, 2020, p. 1). The researchers (ibid., p. 6) indicate that *"in addition to low-grade inflammation and an anti-white matter autoimmune response, EHS can also be diagnosed by the presence of oxidative/nitrosative stress."* This finding indicates that EHS is a very real phenomenon that has significant public health consequences as RFR becomes ubiquitous and physicians recognise "*that EHS is a neurologic pathological disorder which can be diagnosed, treated, and prevented. Because EHS is becoming a new insidious worldwide plague involving millions of people"* (ibid., p. 1).

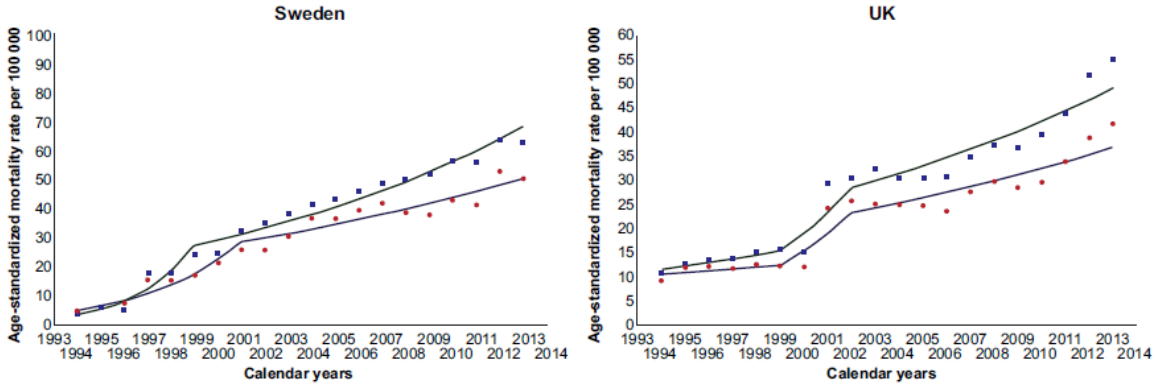

Figure 4 Figure 5 Trends in mortality from Alzheimer's disease in the European Union, 1994–2013.

The most troubling neurodegenerative condition facing modern society is Alzheimer's Disease. Stefi et al. (2019) find evidence that RFR promotes molecular pathogenic mechanisms associated with Alzheimer's Disease. A possible link between electromagnetic fields and the occurrence of Alzheimer's Disease has long been noted (Sobel et al., 1995). However, there is a concern as to the increasing incidence of and deaths from this neurodegenerative disease (Vieira et al. 2013), particularly the increasing trend since the 1990s (Niu et al., 2017). Figure 1 illustrates the trend in mortality from the disease comparing males and females. Note the growth in the incidence of mortality in the UK which far outstrips the age at which the population is aging. Given the growth in RFR sources across society, researchers are concerned that it may be one of the environmental factors responsible for the dramatic increase in the incidence of Alzheimer's even after the, aging population is accounted for (Hallberg and Johansson, 2005; Hallberg, 2015). Hallberg and Johansson (2005) investigated the correlation between the increase in RFR from mobile cellular networks in Sweden and the dramatic increase in the incidence in Alzheimer's Disease and found a direct correlation. We can see from Figure 1 that Sweden, one of the first economies to adopt mobile telephony, has a significant increase in mortality rates that is in lockstep with the growth of RFR sources. The question facing epidemiologists is what are the causal mechanisms between RFR exposure and the risk of Alzheimer's Disease? One common cause of neurodegenerative diseases is oxidative stress in CNS cells (Paloczi et al. 2018), and this condition is strongly linked

with Alzheimer's Disease (Butterfield, Howard, and LaFontain, 2001; Tönnies and Trushina, 2017).

What are the biological mechanisms that produce ill-health in children and adults?

The monograph titled the *Non-Thermal Effects and Mechanisms of Interaction Between Electromagnetic Fields and Living Matter* (Giuliani and Soffriti, 2010) was the first to systematically report on the biophysical mechanisms, cellular mechanisms and tissue effects of EMFs and RFR. It also presented a summary of the state of extant *in vivo* and epidemiological research to 2010. There are many known carcinogens and environmental toxins for which the operative mechanisms are not fully known nor understood. This did not prevent their classification by the IARC nor their acceptance as carcinogenic or toxic effects on human biological systems (Michaels, 2008). As Giuliani and Soffriti (2010) demonstrated and subsequent research confirmed there is a range of generally accepted mechanisms at play in producing physical and biological effects.

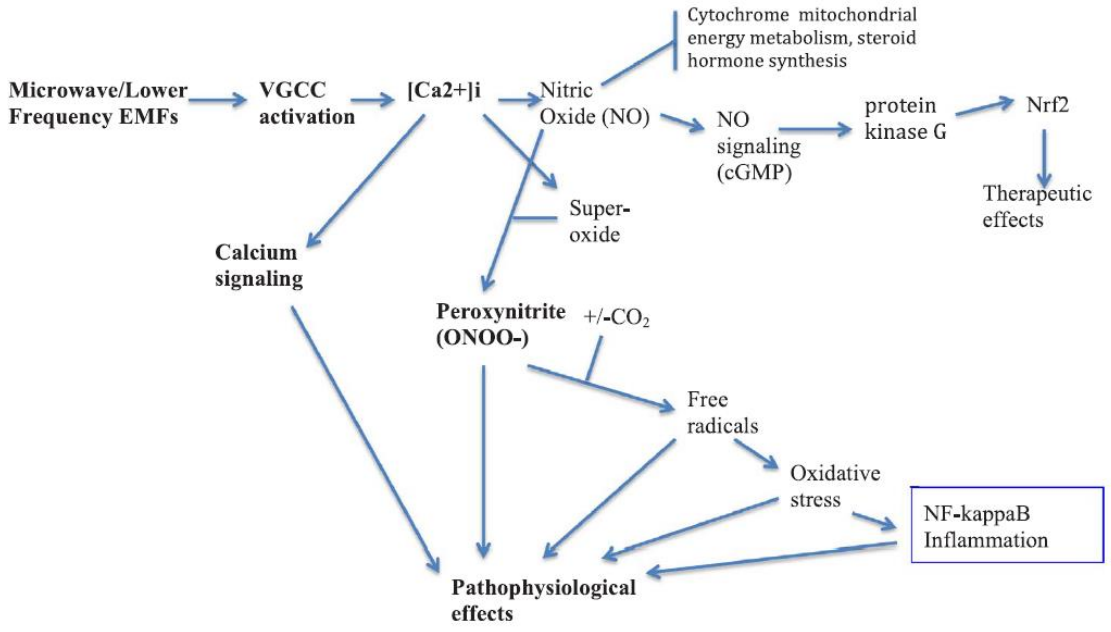

Figure 6 Mechanisms and Pathways to Pathophysiological Effects (Reproduced from Pall 2018)

While the direct effects of certain carcinogens and biological toxins are widely acknowledged, research illustrates that *"carcinogens may also partly exert their effect by generating reactive oxygen species (ROS) during their metabolism. Oxidative damage to cellular DNA can lead to mutations and may, therefore, play an important role in the initiation and progression of multistage carcinogenesis…Elevated levels of ROS and down regulation of ROS scavengers and antioxidant enzymes are associated with various human diseases including various cancers. ROS are also implicated in diabetes and neurodegenerative diseases"* (Waris and Ashan, 2006). Thus, researchers have focused on these vectors in arriving at an understanding of causality between RFR and its effects on humans.

Research on RFR, particularly pulsed microwave signals in mobile phone and WiFi sources, has demonstrated that they produce elevated levels of reactive oxygen species (ROS), which in turn cause oxidative stress in cells (De Iuliis et al., 2009; Georgiou, 2010; Nazıroğlu, et al., 2013; Yakymenko et al., 2016). Oxidative stress is caused by an imbalance between ROS and the counter effects of antioxidants that help detoxify and repair biological systems. Thus, the body normally employs antioxidant defence mechanisms to counter ROS and help avoid diseases such as cancer, which are triggered by oxidative stress and its tendency to cause strand breaks in cellular DNA. A raft of studies indicates that a chain of biological mechanisms produces oxidative stress and the observed negative health outcomes in laboratory animals and humans. Martin Pall, Professor Emeritus of Biochemistry and Basic Medical Sciences, at Washington State University points to the role of voltage-gated calcium channel (VGCC) activation triggered by RFR sources such as 2-5G and WiFi, as being one of the primary causal mechanisms (Pall, 2018). Panagopoulos (2019) points out that *"experimental results are in agreement with the "ion forced oscillation mechanism" for irregular gating of electro-sensitive ion channels on cell membranes… the "ion forced-oscillation mechanism"… and may lead to disruption of the cell's electrochemical balance and function … The validity of this mechanism has been verified by computer numerical test"* (cf. Panagopoulos et al. 2000, 2002). In his review published in 2018, Professor Pall cites over 120 empirical research papers in support of his thesis. Thus, this is further support for the cumulative body of evidence which refutes the proposition that RFR has no biological effects, other than local thermal effects on tissue. Professor Pall's earlier 2013 review paper cites 22 research studies that specifically point to the role played by VGCC activation (Pall, 2013). The number of studies replicating experiments that corroborate this theory has grown significantly, while none appear to refute it. Figure 1 illustrates the posited mechanisms, pathways, and outcomes. A detailed discussion is beyond the scope of this report, however, several important mediating mechanisms and patho-physiological outcomes are now discussed.

A review of scientific studies by Kesari et al. in 2013 concluded that relatively brief, regular, and also long-term use of microwave devices results in negative impacts on biological systems, especially the brain (Kesari, 2013). This review squarely highlights the role played by reactive oxygen species (ROS) as a key mechanism (generated by exposure to microwaves) in producing serious negative effects in living organisms. Exposure to ionizing radiation has been long known to disturb the balance between ROS and the antioxidants that neutralise them. Usually this imbalance results in a high probability that the subject will develop cancers and other chronic conditions.

A wealth of studies now illustrate, however, that non-ionizing radiation emitted from smartphones, cordless phones, WiFi, Bluetooth and other wireless technologies, such as those powering the Internet of Things (IoT) can severely disturb this balance also, by amplifying ROS, suppressing antioxidants, and increasing oxidative stress (Belpomme et al., 2018). There is substantial evidence that oxidative damage to cellular proteins, lipids, and DNA is at the root cause of many of the ill-effects of microwave RFR. Most worrying in all of this is that scientists have found that the mutagenic effects on the DNA of living cells occur under the low-levels of exposure to the pulsed microwave radiation found in most of these devices. (This is discussed below in some detail.) The consequences for children are obvious, given their greater exposure levels and susceptibility to health ill-effects and also that their bodies are constantly growing and developing (Kheifets, 2005; Han et al., 2010).

A recent study illustrates the relatively low level of exposure required to produce adverse biological effects. Chauhan et al. (2017) published the results of their experiment on Wistar rats. The rats in this experiment were exposed to RFR at 25% of the normal level in the human ear and 15% of that level, for 2 hours per day for 35 days. Autopsies of the rats exposed to RFR

revealed significantly high levels of ROS in their livers, brains, and spleens. Besides, histological changes were also found in brains, livers, testes, kidneys, and spleens. In line with a wealth of other similar studies, the researchers concluded that the *"results indicate possible implications of such exposure on human health."* Earlier studies found that rat brains exposed to RFR exhibited an increase in single-strand DNA breaks and chromosomal damage in brain cells. Thus, it is beyond doubt that the substantial increase in ROS in living cells under RFR at low signal strength could be causing a broad spectrum of health disorders and diseases, including cancer, in humans and particularly in children. Certainly, recent studies have provided significant empirical evidence to support this theory (Belpomme et al. 2019).

Russian scientist Dr. Yuri Grigoriev, Chairman of the Russian National Committee on Non-ionizing Radiation Protection (RNCNIRP) points out that *"National and international regulatory limits for radiofrequency radiation (RFR) exposure from cell phones and cell towers are outdated"* (Grigoriev, 2017). He argues that Western standards are inadequate to protect human health, in contrast with those in Russia, especially where the health of children is concerned. In Belpomme et al. (2018), whose authors include cancer researchers, it is argued that *"In spite of a large body of evidence for human health hazards from non-ionizing EMFs at intensities that do not cause measurable tissue heating, summarized in an encyclopaedic fashion in the Bioinitiative Report (www.bioinitiative. org), the World Health Organization (WHO) and governmental agencies in many countries have not taken steps to warn of the health hazards resulting from exposures to EMFs at low, non-thermal intensities, nor have they set exposure standards that are adequately health protective."*

Thus, there is almost unanimous agreement that the property of RFR to place human cells into oxidative stress lies at the core of almost all health risks, as indicated above (Yakymenko et al., 2016). The generation of reactive oxygen species (ROS) is central. Recent studies of people living in proximity to mobile base stations found evidence for elevated levels of ROS in their blood, which is a biochemical indicator of oxidative stress, indicating that they are exposed to greater risks of ill-health (Zothansiama et al., 2017). The CNS appears to be the most vulnerable human biological system, with neurodegenerative diseases, neurobehavioral (including problems with learning and development in children), and immunological problems the source of greatest concern to scientists (Barnes and Greenebaum, 2020; Belpomme et al. 2018; Belyaev et al. 2016; Di Ciaula, 2018; Miller et al., 2018; Russell, 2018, among many others). Rigorous experimental studies on laboratory rats have found that daily exposures to low levels of microwave radiation, such as that emitted by WiFi devices, similar to those being introduced in 5G systems, causes significant biological changes in a range of major organs such as the brains, hearts, reproductive systems, and eyes of the rats being studied (Chauhan et al., 2017; Wilke, 2018). Scientists and medical practitioners are concerned about the significant risks placed on the most vulnerable in society, examples including children, pregnant women, those with existing health issues, and senior citizens.

Because PHE and other government agencies look to the ICNIRP[12], and because it ignores the majority of scientific evidence demonstrating harmful non-thermal exposures, UK citizens and their children are exposed to RFR that generates high levels of oxidative stress in their bodies, and which neutralizes the body's antioxidant defence system (Kıvrak et al., 2017). To compound matters even further, one of the significant findings of the NTP study reviewed above was that the presence of RFR promoted the growth of tumours caused by other carcinogens. The findings

[12] https://www.gov.uk/government/publications/mobile-phone-base-stations-radio-waves-and-health/mobile-phone-base-stations-radio-waves-and-health

of the cumulative body of research reviewed herein are objective, and particularly disturbing where children are concerned.

3. DO THE HEALTH AND SAFETY GUIDELINES PROTECT PUBLIC HEALTH?

UK policymakers look to Public Health England (PHE) to assess the safety of non-ionising RFR. The PHE's position on this draws heavily upon two reports by the Advisory Group on Non-ionising Radiation (AGNIR). These were published in 2012 and 2017. The Department of Health's Committee on Medical Aspects of Radiation in the Environment (COMARE) also looks to the AGNIR reports for guidance. It is therefore incredible that when it issued its last report, ICNIRP members, from the NGO based in Munich, constituted 30% of the 18 member UK committee. Note that AGNIR's primary role was to assess the ICNIRP's safety guidelines, which reflect industry interests not those of public health. In no other regulated sector or area of business activity would this be acceptable from a conflict of interest or corporate governance perspective. ICNIRP scientists were not likely to judge their guidelines unsafe. Thus, they had a significant conflict of interest which compromised the entire decision-making process on UK policy towards RFR and public health, specifically, the introduction of 5G.

The ICNIRP's 2020 guidelines published in March of this year update those published in 1998. The new guidelines include only minor changes to the 1998 guidelines, primarily to accommodate 5G's extremely high-frequency millimeter RFR signals (Barnes and Greenebaum, 2020). It must be remembered the guidelines focus on technical issues and present safety recommendations for the thermal effects of non-ionizing RFR at high-levels of exposure over a short-term measured in minutes. They effectively ignore or deny the existence of non-thermal effects on adults and children and long-term exposure to RFR at low levels. The ICNIRP 2020 Guidelines ignore or dismiss on scientifically spurious grounds the significant body of scientific research since 1998. The majority of independent scientists consider the ICNIRP and the related EU SCENIHR as 'captured' organisations—that is they are heavily influenced by industry-funded researchers and industry itself. The next section addresses the question of why thermal guidelines are not fit for purpose.

Why do the ICNIRP thermal effect threshold guidelines fail to protect the public?

First, a logical observation: *If non-thermal effects occur at relatively low levels of EMF-RFR power densities, then thermal guidelines are insufficient*. The guidelines in question are those published by ICNIRP: the original guidelines were published in 1998, commented upon in 2009, and *"somewhat modified"* in 2020 to accommodate 5G technologies (ICNIRP, 1998, 2009, 2020).

The current ICNIRP guidelines state: *"The main objective of this publication is to establish guidelines for limiting exposure to EMFs that will provide a high level of protection for all people against* ***substantiated adverse health effects*** *from exposures to both short- and long-term, continuous and discontinuous radiofrequency EMFs."* Note the term in bold. To distinguish "adverse health effects", the following methodology was adopted:

> *"ICNIRP first identified published scientific literature concerning effects of radiofrequency EMF exposure on biological systems, and established which of these were both harmful to human health and scientifically substantiated. This latter point is important because ICNIRP considers that, in general, reported adverse effects of radiofrequency EMFs on health need to be independently verified, be of sufficient scientific quality and consistent with current scientific understanding, in order to be taken as "evidence" and used for*

setting exposure restrictions. Within the guidelines, "evidence" will be used within this context, and "substantiated effect" used to describe reported effects that satisfy this definition of evidence. The reliance on such evidence in determining adverse health effects is to ensure that the exposure restrictions are based on genuine effects, rather than unsupported claims. However, these requirements may be relaxed if there is sufficient additional knowledge (such as understanding of the relevant biological interaction mechanism) to confirm that adverse health effects are reasonably expected to occur."

Thus, using what Cherry (2004) described as a *"constructive dismissal"* approach the ICNIRP eliminated the majority of peer-reviewed papers and studies. All these papers had one thing in common. They demonstrated the existence of non-thermal effects at a level far below the ICNIRP guidelines. These non-thermal effects were substantiated by peer-reviewers who were experts in the area and were also subsequently validated by review studies, that were again peer-reviewed. Hence, it may be inferred that the guidelines did NOT provide a high level of protection for ALL people.

Table 1 ICNIRP 2020 Guidelines[13]

Parameter	Freq. range	ΔT	Spatial	Aver. time	Health effect level	RF	Occup.	RF	General public
Core ΔT	100 kHz-300 GHz	1°C	WBA	30 min 6 min	4 W/kg	10	0.4 W/kg	50	0.08 W/kg
Local ΔT (Head & Torso)	100 kHz-6 GHz	2°C	10 g	6 min	20 W/kg	2	10 W/kg	10	2 W/kg
Local ΔT (Limbs)	100 kHz-6 GHz	5°C	10 g	6 min	40 W/kg	2	20 W/kg	10	4 W/kg
Local ΔT (Head, Torso, Limbs)	>6-300 GHz 30-300 GHz 10-300 GHz	5°C	4 cm^2 1 cm^2 20 cm^2	6 min 6 min $68/f^{1.05}$	200 W/m^2	2	100 W/m^2 200 W/m^2 50 W/m^2	10	20 W/m^2 40 W/m^2 10 W/m^2
Pain (contact current)	100 kHz-110 MHz *(**guidance** level reference level)*	--	--	10 sec	20/10 mA (adult/child)	1	20 mA 40 mA	1	20/10 mA (ad./child) 20 mA

The only effects the guidelines protect are thermal effects, as heating is the only physical-biological effect taken into account when setting the protection levels. On that note, the acceptable SAR levels were developed from research in 1988 used to develop the adult head and body phantom of the Standard Anthropomorphic Mannequin (SAM). This is claimed to be protective of children of all ages to adulthood. However, this is in question as the SAM is based on the 98th percentile of military recruits in 1988, that weigh 220 lbs and have a 12 lb head—that is a 6'2", 220 lbs. large adult male. This represents just 3% of cell phone users or those exposed to other sources of RFR (Gandhi et al., 2012). As Ghandi et al. demonstrate this does NOT protect children.

[13] https://www.anfr.fr/fileadmin/mediatheque/documents/expace/workshop-5G/20190417-Workshop-ANFR-ICNIRP-presentation.pdf

As Table 1 indicates, below 6 GHz, thermal effects are measured using the Specific Absorption Rate (SAR). As indicated, this is measured in watts per kilogram (W/kg) and it is the rate at which RFR energy is estimated to be absorbed per unit mass of tissue. The IEEE (1992) standard, based on the SAM, allows whole-body average SAR exposure to 0.08 W/kg averaged over 30 min, and the spatial peak SAR for any 1 gram of tissue to 1.6 W/kg averaged over 30 min. The occupational exposure is 6 minutes at an energy level that produces this. The standard was adopted by the FCC in 1996. The FCC guidelines are based on a 4 W/Kg adverse thermal level effect observed in laboratory animals. The ICNIRP (1998) Guidelines determine compliance to this standard with FCC approval in 2001. The FCC exposure for the general population is *"0.08 W/kg as averaged over the whole body and spatial peak SAR not exceeding 1.6 W/kg as averaged over any 1 gram of tissue (defined as a tissue volume in the shape of a cube). Exceptions are the hands, wrists, feet, and ankles where the spatial peak SAR shall not exceed 4 W/kg, as averaged over any 10 grams of tissue (defined as a tissue volume in the shape of a cube) [averaged over 30 minutes]."* The maximum power density is 10 W/m^2. The ear and limbs have a spatial peak SAR not exceeding 4 W/kg, as averaged over any 10 grams of tissue averaged over 30 minutes. Based on existing theories and research data, the FCC recognised the safety problems with WiFi and *recommended that such devices are not operated less than 20 cm from the human body for 30 minutes*. However, as far back as 2002, the US Environmental Protection Agency (EPA) stated that the *"FCC's exposure guideline is considered protective of effects arising from a thermal mechanism but not from all possible mechanisms. Therefore, the generalisation by many that the guidelines protect human beings from harm by any or all mechanisms is not justified"* (Hankin, 2002). This observation also applies to the ICNIRP guidelines. The EPA's reservations were justified, given research findings published over the past 18 years (to 2020) that refute the theory that hazards were confined to thermal effects.

A detailed critique of the ICNIRP draft guidelines and its Appendix B

One of the most important critiques of the ICNIRP Guidelines was provided in its draft stage by Professor Martin Pall and published in 2018. It will come as no surprise to find that the final guidelines (ICNIRP, 2020) failed to incorporate Professor Pall's comments. The following extract summarises these points:

> ***"Serious flaws in 2018 ICNIRP draft guidelines and appendix B***
>
> *1. The biological portions of these ICNIRP drafts … have 64 different claims for which no evidence is provided. Each of these 64 claims should be documented in terms of the larger scientific literature, not just by cherry picking one or a few studies that can be claimed to support the ICNIRP position. This is particularly important because there is a very large literature contradicting many of these claims.*
>
> *2. Among the most egregious claims are the undocumented claims that certain EMF effects have no demonstrated health impacts. It is our belief that most, if not all, EMF effects have demonstrated health impacts, as shown by the biomedical scientific literature. Claims of no demonstrated health impacts must, therefore, be based on an extensive review of the biomedical literature on what health effects, if any, are produced by each EMF effect.*
>
> *3. The conditions used in a study determine what results are obtained. Therefore, a study done under one set of conditions cannot conflict with or show inconsistencies with another done under another set of conditions. The only way to show conflicts or inconsistencies is to do identical studies and produce different results. ICNIRP and other similar organizations open suggest that there are conflicts or inconsistencies based on some*

superficial similarities, while providing no evidence whatsoever that any such inconsistencies actually exist. This is, therefore, a fundamental logical flaw that needs to be corrected in the ICNIRP draft."

A detailed but abridged extract from Professor Pall's *"Critiques of biological parts of ICNIRP draft"* follows, while Appendix C presents the reviews he cites supporting his detailed critique. While several other responses to ICNIRP are available, this provides the most comprehensive evidence of the flaws in the ICNIRP guidelines. Significantly, however, it demonstrates the continued use of the "constructive dismissal" approach in action and a fundamental departure from the Bradford Hill Guidelines. Note 119 signatures were supporting his submission to ICNIRP to Professor Pall's documentation supporting the contention that the ICNIRP Guidelines fail to protect human health.

1. ***"Neurological and/or neuropsychiatric effects that occur at microwave frequencies***

ICNIRP claims that frequencies above 10 MHz are not known to stimulate nerves. However, 27 different reviews listed in [Appendix C herein] show that there are neurological and/or neuropsychiatric effects that occur at microwave frequencies. This claim is therefore false and must be deleted.

2. ***Non-thermal effects of microwave frequency electromagnetic fields (EMFs)***

2018 ICNIRP draft guidelines, subsect. 4.3.3 (Temperature elevation):

> *"For very low exposure levels (such as within the ICNIRP (1998) basic restrictions), there is extensive evidence that the amount of heat generated is not sufficient to cause harm, but for exposure levels above those of the ICNIRP (1998) basic restriction levels, yet below those shown to produce harm, there is still uncertainty."*

ICNIRP provides no evidence for this claim, which is falsified by each of the 89 reviews listed in Appendix C. If ICNIRP wishes to argue against those findings, it should first cite each review, discuss in detail the findings reported and then attempt to rebut each of those 89 bodies of evidence.

3. ***Electromagnetic hypersensitivity or EHS***

2018 ICNIRP draft guidelines, appendix B, sect. 2.2 (Symptoms and wellbeing):

"A small portion of the population attributes non-specific symptoms to various types of radiofrequency EMF exposure; this is referred to as Idiopathic Environmental Intolerance attributed to EMF (IEI-EMF). Double-blind experimental studies have consistently failed to identify a relation between radiofrequency EMF exposure and such symptoms in the IEI-EMF population, as well as in healthy population samples. These human experimental studies provided evidence that 'belief about exposure' (e.g. the so-called 'nocebo' effect), and not exposure itself, is the relevant symptom determinant."

No evidence is provided in support of these assertions.

4. ***Associations between exposure and symptoms or well-being***

2018 ICNIRP draft guidelines, appendix B, sect. 2.2 (Symptoms and wellbeing):

"In studies on transmitters, no consistent associations between exposure and symptoms or wellbeing were observed when objective measurements of exposure were made, or when exposure information was collected prospectively."

No evidence is provided in support of this assertion.

2018 ICNIRP draft guidelines, appendix B, sect. 2.2 (Symptoms and wellbeing):

"In studies on mobile phone use, associations with symptoms and problematic behavior have been observed. However, these studies can generally not differentiate between potential effects from radiofrequency EMF exposure and other consequences of mobile phone use, such as sleep deprivation in adolescents using the mobile phone at night."

No evidence is provided in support of this claim.

2018 ICNIRP draft guidelines, appendix B, sect. 2.2 (Symptoms and wellbeing): "Overall, the epidemiological research does not provide evidence of a causal effect of radiofrequency EMF exposure on symptoms or well-being."

No evidence is provided in support of this claim. The same 26 reviews on neurological /neuropsychiatric effects that were referred to above also falsify these ICNIRP claims regarding cell phone effects. Similar effects were found, including sleep disruption, fatigue, headache, memory dysfunction, depression, lack of concentration, anxiety, sensory dysfunction and several others. These were found to be produced by many different types of EMF exposures. These included radar, other occupational exposures, three types of broadcast radiation, heavy cell phone use, living near cell phone towers and microwave radiation of the US embassy in Moscow. Clearly these are not caused by behavioral changes specific for cell phone use, as ICNIRP argues here. When these problems are becoming almost universal in every single technologically advanced country on earth, surely it is time for ICNIRP to start protecting us from them.

5. High frequency EMF exposure affects symptoms

2018 ICNIRP draft guidelines, appendix B, sect. 2.2 (Symptoms and wellbeing):

"There is thus no evidence that high frequency EMF exposure affects symptoms, except for pain and potentially tissue damage) at high exposure levels."

No evidence is provided in support of this claim. It is shown to be completely untrue by the 27 reviews on neurological/neuropsychiatric effects previously discussed.

6. Physiological functions and adverse health effects

2018 ICNIRP draft guidelines, appendix B, sect. 2.3 (Other brain physiology and related functions):

"A number of studies of physiological functions that could in principle lead to adverse health effects have been conducted, primarily using in vitro techniques. These have included multiple cell lines and assessed such functions as intra- and intercellular signaling, membrane ion channel currents and input resistance, Ca_2ti dynamics, signal transduction pathways, cytokine expression, biomarkers of neurodegeneration, heat shock proteins, and oxidative stress-related processes. Some of these studies also tested for effects of co-exposure of radiofrequency EMF with known toxins. Although some effects have been reported for some of these endpoints, there is currently no evidence of effects relevant to human health."

No evidence is provided in support of these claims. Is ICNIRP really trying to argue that important signalling pathways, excessive intracellular calcium, inflammation including inflammatory cytokines, neurodegeneration, heat shock responses and oxidative stress have "no relevance to human health"? If so, ICNIRP needs to debunk hundreds of thousands of studies in the PubMed database.

7. Evidence of eye damage

2018 ICNIRP draft guidelines, appendix B, sect. 2.3 (Other brain physiology and related functions):

"Some evidence of superficial eye damage has been shown in rabbits at exposures of at least 1.4 kW m-2, although the relevance of this to humans has not been demonstrated."

Why does ICNIRP state that there is no evidence of human relevance but never tells us if there is any evidence that the findings are not relevant to humans? If there is simply a lack of evidence, then the way ICNIRP describes this speaks to an unconscionable bias on the part of ICNIRP. With human relevance, as with all things, absence of evidence is not evidence of absence.

8. Endocrine, including neuroendocrine systems, impacted by non-thermal EMF exposures

In contrast with the many ICNIRP statements with no evidence provided, the endocrine, including neuroendocrine systems, have been widely found to be impacted by non-thermal EMF exposures as shown by the following 12 reviews [Glaser, Z., 1971; Tolgskaya and Gordon, 1973; Raines, 1981; Hardell and Sage, 2008; Makker et al. 2009; Gye and Park, 2012; Pall, 2015; Sangün et al. 2016; Hecht, 2016; Asghari et al. 2016; Pall, 2018; Wilke, 2018].

If ICNIRP wishes to disagree with the findings in these reviews, it should cite each of these reviews and describe what findings were documented in each of them. Only then could ICNIRP feel free to disagree with any conclusions reached. Ignoring vast amounts of contrary data and opinion undercuts any claim that ICNIRP may make to providing unbiased science.

9. Neuronal cell death following non-thermal EMF exposures

2018 ICNIRP draft guidelines, appendix B, chap. 5 (Neurodegenerative Diseases):

"Although one group has reported that exposure to pulsed radiofrequency EMF fields increased neuronal death in rats, which might contribute to an increased risk of neurodegenerative disease, two studies have failed to confirm these results."

No evidence is provided in support of this claim. This is completely inaccurate: approximately a dozen studies found elevated levels of neuronal cell death following non-thermal EMF exposures reviewed in the Tolgaskya and Gordon 1973 review. The two studies by Zhang et al. (2017) in rats showed that repeated pulsed microwave/RF radiation in young rats caused them to develop Alzheimer's-like effects as middle-aged rats, including elevated levels of amyloid beta protein and oxidative stress in their brains and including Alzheimer's-like behavioral and memory deficiencies. Other studies have found increased levels of amyloid beta protein following EMF exposures. Why is ICNIRP ignoring such evidence?

10. Link between radiofrequency EMF exposure and measures of cardiovascular health

2018 ICNIRP draft guidelines, appendix B, chap. 6 (Cardiovascular System, Autonomic Nervous System, and Thermoregulation):

"Numerous human studies have investigated indices of cardiovascular, autonomic nervous system, and thermoregulatory function, including measures of heart rate and heart rate variability, blood pressure, body, skin and finger temperatures, and skin conductance. Most

studies indicate there are no effects on endpoints regulated by the autonomic nervous system."

No evidence is provided in support of this claim.

"The relatively few reported effects of exposure were small and would not have an impact on health."

No evidence is provided in support of this claim.

"The changes were also inconsistent and may be due to methodological limitations or chance."

No evidence is provided in support of this claim. Again, the only way to show inconsistency is to perform identical studies that produce widely different findings. If ICNIRP has such studies, it should produce them. If it does not, it should stop falsely claiming inconsistency when one may be looking simply at variation due to changes in the conditions used. When ICNIRP claims there are methodological problems, these need to be clearly stated and clearly documented.

11. Non-thermal radiofrequency EMF exposures produce autoimmune responses*.*

2018 ICNIRP draft guidelines, appendix B, chap. 7 (Immune System and Haematology):

"There have been inconsistent reports of transient changes in immune function and haematology following radiofrequency EMF exposures."

No evidence is provided in support of this claim.

"These have primarily been from in vitro studies, although some in vivo animal studies have also been conducted."

No evidence is provided in support of this claim.

"There is currently no evidence that such reported effects, if real, are relevant to human health."

A total of 11 animal studies in the EMF Portal database show that non-thermal radiofrequency EMF exposures produce autoimmune responses. These can be easily found by searching that database for autoimmune or autoimmunity for EMFs over 10 MHz. If ICNIRP wishes to argue that these findings are irrelevant to the large increases in autoimmune incidence and prevalence we have seen in recent years in humans, it should make whatever argument it feels is appropriate. To have ICNIRP ignoring this pattern of evidence is unacceptable.

12. Effects of radiofrequency EMF exposure on reproduction and development

2018 ICNIRP draft guidelines, appendix B, chap. 8 (Fertility, Reproduction, and Childhood Development):

"There is very little human experimental research addressing possible effects of radiofrequency EMF exposure on reproduction and development. What is available has focused on hormones that are relevant to reproduction and development, and as described in the Neuroendocrine System section above, there is no evidence that they are affected by radiofrequency EMF exposure."

This is completely untrue. There are 13 studies showing that such EMFs impact human male reproduction, including sperm motility and aberrations in sperm structure; long-term exposures produce decreases in sperm count. These impacts are shown in the following studies:

1. *Avendano, Mata AM, Sanchez Sarmiento CA. 2012 Use of laptop computers connected to the internet through Wi-Fi deceases human sperm motility and increases sperm DNA fragmentation. Fertil Steril 97: No. 1, January 2012 0015-8282.*

2. *Agarwal A, Desai NR, Makker K, Varghese A, Mouradi R, Sabanegh E, Sharma R. 2008 Effects of radiofrequency electromagnetic waves (RF-EMW) from cellular phones on human ejaculated semen: an in vitro pilot study. Fertil Steril 92: 1318-1325.*

13. Prenatal exposure to EMF non-thermal radiation can produce neurological effects

2018 ICNIRP draft guidelines, appendix B, chap. 8 (Fertility, Reproduction, and Childhood Development):

"Other research has addressed this issue by looking at different stages of development (on endpoints such as cognition and brain electrical activity), in order to determine whether there may be greater sensitivity to radiofrequency fields during these stages."

No evidence is provided in support of this claim.

2018 ICNIRP draft guidelines, appendix B, chap. 8 (Fertility, Reproduction, and Childhood Development):

"There is currently no evidence that developmental phase is relevant to this issue."

No evidence is provided in support of this claim. Six studies have found that late prenatal EMF non-thermal exposures in rodents produce long-term neurological changes that are maintained as adults, changes similar to those found in ADHD or autism. No similar changes are produced in adults. These changes were found to be produced by cell phone radiation, cordless phone radiation and by Wi-Fi, suggesting that prenatal exposure to a broad range of such radiation can produce these effects.

14. EMF exposure has an important role in cancer causation

2018 ICNIRP draft guidelines, appendix B, chap. 9 (Cancer):

"There is a large body of literature concerning cellular and molecular processes that are of particular relevance to cancer. This includes studies of cell proliferation, differentiation, and apoptosis-related processes, proto-oncogene expression, genotoxicity, increased oxidative stress, and DNA strand breaks. Although there are reports of effects of radiofrequency EMF on a number of these endpoints, there is no substantiated evidence of health-relevant effects."

No evidence is provided in support of this claim. What ICNIRP is apparently claiming is that these effects of EMF exposure, each of which has been shown in an extraordinarily large scientific literature to have an important role in cancer causation, are—inexplicably—not relevant to health! We are relying on the Melnick critique to provide a much broader-ranging assessment of the many flaws in this cancer section of the ICNIRP draft. We urge ICNIRP to pay close attention to the Melnick critique.

Appendix C [herein] contains reviews documenting each of eight different non-thermal EMF effects. These effects are as follows:

1. *Effects on cellular DNA including single-strand and double-strand breaks in cellular DNA and on oxidized bases in cellular DNA; also evidence for chromosomal mutations produced by double strand DNA breaks (23 reviews).*

2. *Lowered fertility, including tissue remodeling changes in the testis, lowered sperm count and sperm quality, lowered female fertility including ovarian remodeling, oocyte (follicle) loss, lowered estrogen, progesterone and testosterone levels (that is sex hormone levels), increased spontaneous abortion incidence, lowered libido (19 reviews).*
3. *Widespread neurological/neuropsychiatric effects (27 reviews). 4. Apoptosis/cell death (an important process in production of neurodegenerative diseases that is also important in producing infertility responses) (13 reviews).*
5. *Oxidative stress/free radical damage (important mechanisms involved in almost all chronic diseases; direct cause of cellular DNA damage) (21 reviews).*
6. *Endocrine, that is hormonal effects, including neuroendocrine, peptide and other non-steroid hormones; also steroid hormones (12 reviews).*
7. *Increased intracellular calcium: intracellular calcium is maintained at very low levels (typically about 2 X 10-9 M) except for brief increases used to produce regulatory responses, such that sustained elevation of intracellular calcium levels produces many pathophysiological (that is disease-causing) responses) (16 reviews).*
8. *Cancer causation by EMF exposures (36 reviews).*

ICNIRP appears to be systematically avoiding citing and discussing review articles that discuss contrary findings and express contrary opinions to those expressed by ICNIRP. That is not acceptable. If ICNIRP wishes to take a position contrary to those taken in these reviews, at a minimum, ICNIRP must cite each contrary review, discuss its main findings and only then can ICNIRP argue against the positions taken in these reviews."

A constructive critique of the ICNIRP guidelines

Eminent scientists Frank Barnes and Ben Greenebaum, among hundreds of others, find issues with these guidelines viz. *"Current limits for exposures to non-ionizing electromagnetic fields (EMF) are set, based on relatively short-term exposures. Long-term exposures to weak EMF are not addressed in the current guidelines. Nevertheless, a large and growing amount of evidence indicates that long-term exposure to weak fields can affect biological systems and might have effects on human health. If they do, the public health issues could be important because of the very large fraction of the population worldwide that is exposed."* (Barnes and Greenebaum, 2020) This is a strong and suitably restrained statement, as is the norm for scientists.

Barnes and Greenebaum (2020) review a relevant subset of the literature reviewed herein and provide a succinct summary of the issues:

> *"The results of these papers have not been considered convincing or relevant by the [ICNIRP and WHO] panels due to methodological issues, because they did not relate closely enough to human health, and because the experimental results are mixed, showing increases, decreases, or no change in similar situations. However, taken as a group they do provide strong evidence that weak EMF can be sensed by biological systems, as well as suggestive evidence that fields may affect human health.*
>
> *At least part of the explanation for the mixed results is likely to be that biological feedback processes often cancel out perturbations that would otherwise take biological systems out of their normal operating range [Vijayalaxmi et al., 2014]. For example, if we exercise, the body temperature starts to rise, and we begin to sweat in order to limit the*

temperature rise to within the normal operating range. If we get cold, we start to shiver. With EMF we appear to be modifying oxidative stress [De Iuliis et al., 2009; Castello et al., 2014; Usselman et al., 2014, 2016], cancer cell growth rates [Castello et al., 2014; Usselman et al., 2014, 2016; Sherrard et al., 2018], membrane potentials [Ye and Kaszuba 2019], and concentrations of calcium, reactive oxygen species (ROS), superoxide (O_2-), nitric oxide (NO), hydrogen peroxide (H_2O_2), and intercellular pH [Cichon et al., 2017; Gurhan et al., 2020; Osera et al., 2015; Sonntag, 1998]. The body reacts to bring these levels back to within the normal operating range, but there is a time delay in these feedback processes. For periodic inputs, this can lead to either amplification or attenuation of the perturbation. There are many oscillating systems in the body, so the timing of the perturbation makes a difference, just as it does in how pushing a swing at the peak accelerates it, while pushing in the same direction at the bottom slows it down. Dröge [2002] reviews data on oxidative stress that show oxidative stress may be increased by a factor of ten or more for short times during exercise and returns to the normal range upon relaxation. He also shows that long term elevations of the ROS lead to a shift in the baseline levels, and the elevated levels are associated with cancer, aging, and Alzheimer's. The effects of oxidative stress and other radicals are covered in detail by Halliwell and Gutteridge [2015]."

Barnes and Greenebaum (2020) call for additional research to identify new guidelines that limit levels of exposure to mitigate the risks. They argue that *"Eventual guidelines might suggest limiting cell phone calls to X hours per day with exposure levels above Y W/m^2, and for Z days per week exposure should be less than Y W/m^2 to allow the body to reset its baseline. The time between heavy exposures might be initially estimated by looking at recovery times from other stresses such as exercise … A possibility might be that cell phones and WiFi are turned off at night or over the weekend to allow for resetting of the oxidative baseline levels."* In order to understand fully the issues, it is necessary to examine the relevant guidelines.

FCC guidelines propose a maximum power density of 10 W/m^2 or 1,000 μW/cm^2. Note that this maximum power density protects from thermal or heating health effects only. All wireless devices used in the US go through a formal FCC approval process to ensure that the maximum allowable level when operating at the device's highest possible power level is not exceeded. This also applies to the EU.

The ICNIRP Guidelines specify the following: *"below about 6 GHz, where EMFs penetrate deep into tissue (and thus require depth to be considered), it is useful to describe this in terms of "specific energy absorption rate" (SAR), which is the power absorbed per unit mass (W kg−1). Conversely, above 6 GHz, where EMFs are absorbed more superficially (making depth less relevant), it is useful to describe exposure in terms of the density of absorbed power over area* (W m−2), which we refer to as *"absorbed power density."* General public exposures from 100 kHz to 6 GHz are 0.08 W/kg (whole-body), 2 W/Kg (head and torso), 4 W/kg (limbs). Table 1 presents an overall analysis of the 2020 Guidelines. Note that the power density is now set at 20 W/m^2 (>22db) and 40 W/m^2 (>25db) for frequencies 6-300GHz and at spatial exposures of 4 cm^2 and 1 cm^2: What this means is that the iris of the eye of a child (1 cm^2) could be exposed to 40 W/m^2 of a focused mmWave 5G beam for 6 minutes. In contrast, the eye of a 5G engineer could be exposed to 200 W/m2 (>33db) for 6 minutes. Taking the previous guidelines with 10 W/m^2 (20 db) maximum power density, that means a doubling or quadrupling of exposures for the general population and quadrupling for engineers.

It is significant, and extremely worrying, that tumour-promoting effects were observed by Lerchl et al. (2015*) "at low to moderate exposure levels (0.04 and 0.4 W/kg SAR), thus well below*

exposure limits for the users of mobile phones." The authors conclude that their *"findings may help to understand the repeatedly reported increased incidences of brain tumors in heavy users of mobile phones."*

It is for such reasons that the European Academy for Environmental Medicine (EUROPAEM) argues that *"For all RF-based non-thermal EMF effects, SAR estimates are not an appropriate exposure metric, but instead either the field intensity or power density (PD) in combination with exposure duration should be used in safety standards. In contrast to the ICNIRP guidelines, the Russian safety standards, are based on non-thermal RF effects, which were obtained by several research institutes in the former Soviet Union during decades of studies on chronic exposures to RF"* (Belyaev et al., 2016).

In contrast to the FCC and European regulatory agency thermal safety levels, the European Academy for Environmental Medicine (EUROPAEM) EMF Guidelines (Belyaev et al. 2016) indicate a non-thermal safety level of 10 $\mu W/m^2$ or 0.001 $\mu W/cm^2$ daytime exposure and 1 $\mu W/m^2$ nighttime, with 0.1 $\mu W/m^2$ being the limit for sensitive populations (Ibid.). This is 1,000,000 to 100,000,000 times less, in terms of permitted exposure than the FCC Guidelines and vastly greater than the new ICNIRP Guidelines. The EUROPAEM guidelines focus on the prevention, diagnosis, and treatment of EMF-related health problems and illnesses, and are based on the Austrian Medical Association Guidelines. However, the precautionary exposure guidelines recommended in the Bioinitiative Report stand at a more stringent 3–6 $\mu W/m^2$ (BioInitiative Working Group, 2012).

A recent conservative industry-oriented meta-review of studies revealed that the average exposure to WiFi in schools was up to approx. 240 $\mu W/m^2$ (Chiaramello et al., 2019) Note, again, that the EUROPEAM recommended daytime exposures for normal adults is 10 $\mu W/m^2$ and 3–6 μW/m2 in the Bioinitiative Report. Following EUROPEAM, the precautionary level for children should sensibly be in the range of 1 to 0.1 $\mu W/m^2$. These levels are between 25 to 2500 times lower than those currently observed in measured exposures in schools. Furthermore, the actual exposures while sitting in front of a device such as an iPad, a laptop, or when also carrying a smartphone, are clearly going to be many times higher, probably somewhere between the average and peak levels reported above. And, if as Morgan et al. (2018) find, *"Children absorb more [microwave radiation] than adults because their brain tissues are more absorbent, their skulls are thinner and their relative size is smaller"*, then children are at significant risk from future 5G technologies. Thus it would seem that there is great uncertainty about the degree of exposure to children and adolescents, and scientifically speaking great risk, whether from near-field or far-field sources.

The bizarre treatments of fetus and children in the ICNIRP guidelines

Perhaps the most bizarre statement in the ICNIRP guidelines is the following: *"Occupationally-exposed individuals are not deemed to be at greater risk than the general public, providing that appropriate screening and training is provided to account for all known risks. Note that* ***a fetus is here defined as a member of the general public****, regardless of exposure scenario, and is subject to the general public restrictions."* First, Peleg, Nativ, and Richter (2018) prove that occupational exposure to RFR, at levels well-below ICNIRP guidelines, increased the risk and incidence of hematolymphatic (HL) cancers in military and occupational settings. They found that RFR exposure was associated with and significantly increased HL cancer risk in the four groups studied across three countries. The findings thus demonstrated a cause-effect relationship between RFR and cancer (Peleg, Nativ, and Richter, 2018).

Note that a fetus is defined as equivalent to a member of the general public. The critique by Professor Pall addresses such matters. Nevertheless, Li et al. (2011, 2012, 2017) demonstrate that exposure to EMF in utero results in miscarriage or adverse health effects in children. See also epidemiological research on the links between far-field exposure to RFR from mobile phone antennae and miscarriage (Zhou et al. 2017) and near-field RFR exposure linked with mobile phone use during pregnancy (Mahmoudabadi et al., 2017). A range of animal experiments (Aldad et al., 2012; Ikinci, et al., 2013; Zhang, 2015; Othman et al., 2017a,b; Kumari et al., 2017) and epidemiological studies identify similar outcomes in children (Divan et al., 2008, 2012;) and demonstrate that mobile phone use by mothers during pregnancy increase the risk of hyperactivity and attention issues with children (Birks et al., 2017).

None of this research is considered by ICNIRP (2020) Guidelines. The following extract from the ICNIRP Guidelines is truly bizarre in terms of the language used.

> ***"Considerations for fetal exposure****. Local SAR heating factors for the fetus, as a function of gestation stage and fetal posture and position, have been determined that take heat exchange between mother and fetus into account ... This research used numerical models of 13-week, 18-week, and 26-week pregnant women. The heating factors of the fetus were several times lower than those of the mother in most cases. However, the largest heating factor was observed when the fetal body position is very close to the surface of the abdomen (i.e., middle and later stages of gestation). These provide 0.1°C kg W−1 as a conservative heating factor for the fetus. Based on these findings, exposure of the mother at the occupational basic restriction of 10 W kg−1 will result in a temperature rise in the fetus of approximately 1°C, which is lower than the operational adverse health effect threshold for the Head and Torso, but results in a smaller reduction factor (i.e., 2) than that considered appropriate for the general public (i.e., 10). It follows that a localized occupational radiofrequency EMF exposure of the mother would cause the temperature to rise in the fetus to a level higher than that deemed acceptable for the general public. Therefore, to maintain fetal temperature to the level required by the general public local SAR restrictions,* ***a pregnant woman is considered a member of the general public in terms*** *of the local SAR restriction."*

Again, no other effect on the fetus is considered other than remote thermal effects, despite the significant body of research that indicates very real risks to mother and child, during pregnancy and post-natal development.

How does the industry influence UK policy and public opinion?

Scientists from the ICNIRP, who are also, as indicated, members of SCENHIR and WHO, are accused of conflicts of interest due to their close ties with industry. An Italian court judgment recently recognised this. In December 2019, Turin Court of Appeal president Dr. Rita Mancuso ruled that research reviews carried out by ICNIRP and its members were biased and could not be trusted in determining whether there was a causal link between wireless cell phone use and brain cancer.[14] The court decided that there was such a link, and its judgment was based on extant independent scientific studies, such as those cited herein.

Industry sectors responsible for harming the environment and human health have been seen to adopt well-articulated pseudoscientific strategies to undermine independent rigorous research

[14] https://www.radiationresearch.org/wp-content/uploads/2020/01/Turin-Verdict-ICNIRP_Judgment-SUMMARY-of-the-Turin-Court-of-Appeal-9042019_EN-min.pdf Original Italian https://www.diritto24.ilsole24ore.com/_Allegati/Free/Ca_torino_vers_1.pdf

aimed at uncovering scientific truth (McGarity and Wagner, 2008). Michaels (2008) illustrates graphically how the tobacco industry hired scientists and commissioned papers to cast doubt on epidemiological and laboratory evidence suggesting the risks to human health of smoking. Michaels illustrates how that industry sowed doubt about science and medical fact *"since it is the best means of competing with the 'body of fact' that exists in the minds of the general public."* This approach has been adopted across industry sectors, including the telecommunications industry and its approach to neutralising concerns about the health risks of RFR. *"Regulatory risk assessment "and the peer review and advisory processes that have shaped RF/MW regulation…have been prone to political manipulation and conflicts of interests leading to various scientific perspectives being marginalised with reluctance on the part of regulators to make decisions that might inconvenience industry interests"* (Maisch, 2009; cf. Oreskes and Conway, 2011; Alster, 2015; Walker, 2017). Thus, through lobbyists, law firms, consulting scientists, targeted scientific research funding and the co-optation of pseudo-independent organisations such as the ICNIRP, the health risks of RFR have been disputed and scientific findings undermined using what Michaels terms *"junk science."* This involved the perverse and biased application of epidemiological approaches and statistical methods to reinterpret valid scientific data in order to arrive at conclusions that support the industry view of no harm or effect. In the current context, that view of no harm held by industry and the ICNIRP posits that easily controlled thermal effects are what matters and that non-thermal effects do not exist.

How policymakers and the public are misled by bad scientists

Science historians Naomi Oreskes and Erik Conway perform a rigorous historical analysis of environmental science and policymaking in *Merchants of Doubt* to demonstrate how scientists and expert advisers colluded with industry and politicians to mislead the public and distort and falsify established scientific knowledge. The role of these scientists was to manufacture doubt in scientific findings that ran counter to industry interests. The most notorious of these were scientists in league with the tobacco industry, who ensured that doubt was indeed the industry's product. Oreskes and Conway (2011) illustrate how conservative ideologues, corporate interests, conflicted scientists and a compliant media diminished public understanding and awareness of man-made climate change and environmental toxins and carcinogens from industry sources. In 2020, in their investigation of the ICNIRP, Dr. Klaus Buchner and Michèle Rivasi experience an *"uncomfortable déjà-vu: many facts and processes that lead to the actual situation whereby European authorities – from the European Commission to most of the member states – simply close their eyes for real scientific facts and early warnings. We have seen exactly the same scenario in the debate on Tobacco, asbestos, climate change and pesticides"* (Buchner and Rivasi, 2020).

This observation is not new. Over 20 years ago evidence provided to the UK House of Commons Science and Technology Committee by investigative science journalist Stewart Fist held that the:

> *"Cellphone industry has become the tobacco industry of the 1990s: I have no doubt whatsoever that the cellphone industry (often in collaboration with the regulators and some governments) have engaged in a massive cover-up of the potential that exists for these problems. The industry has also been totally cavalier in its attitude; it conducted no research into biological effects, and set standards based primarily on electrical interference to electronic circuits.*
>
> *They have employed all the modern tactics of polluting business sectors—like those of the tobacco industry and the pesticide manufacturers. They have responded to questions of safety with:*

— highly aggressive and co-ordinated public relations campaigns worldwide;
— well-funded political lobbying;
— the creation of fake "grassroots" organisations;
— innuendo, slander and defamation of certain scientists;
— threats of advertising revenue withdrawal for editors and publishers;
— junkets for journalists;
— scientific fraud and manipulation of results;
— blocking publication of scientific findings; and
— scientific funding used as bribes."[15]

The analysis of bad science and bad scientists in this section draws heavily on the research monographs of Oreskes and Conway (2011), Michaels (2008, 2009), and Markowitz and Rosner (2013), among others. Their focus is on the tobacco and other polluting industries: however, the findings of their researches are relevant in the current context as the telecommunications and information technology industries have applied the same playbook to manufacture doubt on the health effects of RFR.

Manufacturing scientific doubt at the EPA and its implications for public health

The Tobacco Institute, which was set up by the industry to manufacture doubt. It challenged the scientific basis of all evidence, particularly that provided by the US Environmental Protection Agency (EPA), by arguing that scientists finding health effects such as cancer from tobacco smoke were performing *"bad science."* However, the industry attack on the EPA did not end there. The *Center for Tobacco Research* in conjunction with the *Tobacco Institute* and related industry scientists enjoined in a smear campaign against the EPA to cast doubt on scientific findings by calling such research *"junk science"*. Take, for example, "*The Center for Tobacco Research set up a "special projects" office to deal with secondhand smoke, including the development of countervailing scientific evidence, expert witnesses, and industry-sponsored conferences to challenge the emerging scientific consensus"* (Oreskes and Conway, 2011). In contrast, it can be seen from the evidence provided by Stewart Fist cited above and from other sources adduced herein, that the telecommunications and information technology sectors applied the same tactics as the tobacco and pesticide industries, but in and through different institutional mechanisms (Alster, 2015; Buchner and Rivasi, 2020; Walker, 2017).

Notably, the EPA *"was once a hub of research on RF effects, employing as many as 35 scientists."* Despite efforts by the Regan Administration in the 1980s to neutralise the agency's research program, the EPA continued to investigate the non-thermal effects until the relevant research program was defunded in 1996. In 1990, a comprehensive peer-reviewed study by the EPA concluded that there is reason to believe that "*the findings of carcinogenicity in humans are biologically plausible",* with EMFs as *"a possible, but not proven, cause of cancer in humans"* (McGaughy et al., 1990). Take, for example, the report states that *"it is possible that exposure to EM fields or NIR radiation may present some risk for developing malignant melanomas of the skin."* Thus, from 1975 to 1995, the EPA researched the health effects of RFR and were about to develop EMF safety standards, before it was de-funded. Alster (2015) cites Carl Blackman, a scientist at the EPA until retiring in 2014, as being *"cautious in imputing motives to the high government officials who wanted his work at EPA stopped. But he does say that political pressure has been a factor at both the EPA and FCC: —The FCC people were quite responsive to the biological point of view. But there are also pressures on the FCC from industry. The FCC, he*

[15] https://publications.parliament.uk/pa/cm199899/cmselect/cmsctech/489/489a30.htm

suggests, may not just be looking at the scientific evidence. —The FCC's position—like the EPA's—is influenced by political considerations as well." Thus, the industry effectively neutralised the one independent body in the US performing comprehensive research in the area. Into this emerging regulatory vacuum, came the ICNIRP in 1992. It is significant that through the agency of its founder Michael Repacholi, the ICNIRP had the support of the WHO. However, unlike the EPA and its research on environmental toxins and carcinogens, the ICNIRP, FCC or FDA did not perform empirical research studies on the health effects of RFR[16]. It was not until the National Toxicology Programme (NTP 2018a,b) published its findings, could the agency of any western government claim to have performed empirical research aimed at helping to protect public health against RFR exposure.

In December 1992, the EPA released the findings of its Respiratory Health Effects of Passive Smoking study (Jinot and Bayard, 1992). The report had a strong essential conclusion, but as is the case with many strong studies conducted by reputable scientists it was overly cautious, with key evidence being played down: This included strong evidence of the link with sudden infant death syndrome (SIDS), increased cardiovascular disease in adults, and respiratory infections in children, among others. Scientists are by nature conservative, often overly so, with consequences for public health (Oppenheimer et al., 2019). One area of controversy concerning the EPA study was its inclusion of findings on secondary smoking exposure at 90% as well as the 95% confidence level. Oreskes and Conway (2011) report that the agency accepted *"results at the 90 percent confidence level, but it was a reasoned one, and concluded that there was no magic bullet of risk assessment—different kinds of studies were useful in different ways—so the best approach was to scrutinize all the available evidence and determine where the weight of the evidence lay."*

Rigor and relevance are the two cornerstones of scientific research. However, the focus on rigor has made the findings of many studies irrelevant to society and the communities that scientists serve. In their review of scientists' roles in studying climate change, Oppenheimer et al. (2019) demonstrate that scientists can downplay findings, fail to identify real risks, or significantly underestimate them, with disastrous outcomes for society and public health. Take, for example, Oppenheimer et al. *"noticed a clear pattern of underestimation of certain key climate indicators, and therefore underestimation of the threat of climate disruption. When new observations of the climate system have provided more or better data, or permitted us to re-evaluate earlier conclusions, the findings for ice extent, sea level rise and ocean temperature have generally been worse than previously thought."* They observed that when dealing with policymakers, scientists have a tendency for consensus and are willing to ignore or downplay divergent findings, particularly when it may be controversial. While heated disagreements typically characterise normal science, with competing camps and paradigms in evidence (Kuhn, 2012), scientists from a particular paradigm (e.g. global warming) will agree in public and offer a unified front to policymakers, while often voicing scepticism on particular findings and conclusions within their community. Statistical tools and techniques are used to good effect to strengthen the validity and reliability of scientific findings. However, the same approaches can be used to discredit

[16] Studies of health effects from RFR exposure are categorised as follows: (1) epidemiological studies of human populations and sub-populations (these include, cross-sectional, cohort and case control studies); (2) *in vivo* studies on human and animals in controlled laboratory settings; and (3) *in vitro* studies on cellular and other organisms. These empirical methods for examining cause-effect relationships are complementary but each many have particular strengths and weaknesses. In a weight-of-evidence approach, evidence from all contributes to an overall health risk assessment.

genuine scientific findings or maintain rigor at the cost of relevance and thereby fail to protect public health. We now discuss these research techniques.

Statistical significance underpins good science and its findings. However, Ziliak and McCloskey (2009) argue that *"For the past eighty-five years it appears that some of the sciences have made a mistake, by basing decisions on statistical "significance"… Statistical significance at the 5% or other arbitrary level is neither necessary nor sufficient for proving discovery of a scientific or commercially relevant result… statistical insignificance, is on its own valueless, a meaningless parlor game. Statistical significance should be a tiny part of an inquiry concerned with the size and importance of relationships. Unhappily it has become a central and standard error of many sciences. The history of this "standard error" of science—the past 85 years of mistaking statistical significance for scientific importance."* In the context of its research on secondary smoke, the EPA was correct in adopting its weight-of-evidence instead of a methodological approach that would have ended up dismissing important findings. As Oreskes and Conway (2011) argued in support of the EPA: *"There's nothing magic about 95 percent. It could be 80 percent. It could be 51 percent. In Vegas if you play a game with 51 percent odds in your favor, you'll still come out ahead if you play long enough. The 95 percent confidence level is a social convention, a value judgment. And the value it reflects is one that says that the worst mistake a scientist can make is to fool herself: to think an effect is real when it is not. Statisticians call this a type 1 error. You can think of it as being gullible, naïve, or having undue faith in your own ideas. To avoid it, scientists place the burden of proof on the person claiming a cause and effect. But there's another kind of error—type 2—where you miss effects that are really there. You can think of that as being excessively skeptical or overly cautious."*

These points are echoed by Markowitz and Rosner (2013) who cite political scientist Peter Van Doren as stating *that "Normal science worries more about false positive errors," … and this bias "has the inevitable side effect of increasing" the risk of missing real disease. By requiring a 95 percent confidence level of statistical probability of the proof of danger, an inordinate number of studies inaccurately report no danger when in fact danger does exist. "False negatives," he argues, are a real problem for community studies because the conservative nature of statistical analysis decrees such a high threshold of proof that much meaningful evidence is often rejected in favor of the "null hypothesis" of no causal relationship."* (cf. *Van Doren, 1996).*

Elsewhere in this report, we have cited peer-reviewed primary and secondary research on RFR, including laboratory and epidemiological studies, which reported findings of non-thermal effects at low levels of exposure to RFR at the 95% confidence interval (CI). Thus, such research exceeds the burden of proof demanded of second-hand tobacco smoke, for example, which relied on a 90% confidence interval. The point being made here is that research on RFR exposures and physical and biological health effects more than meets the criteria of good science and exceeds the burden of proof applied to second hand smoke exposures. Thus, the arguments made by the ICNIRP and others to exclude rigorous, valid, and reliable research findings are bogus. We now refer to two of these studies. Environmental toxins and carcinogens are known to cause cancer in laboratory animals—this applies to tobacco smoke and RFR. The NTP (2018a,b) and Ramazzini Institute (Falcioni et al., 2018) studies provide conclusive evidence at unassailable levels of rigour. Thus, as epidemiology has revealed increased rates of cancer in humans, it is reasonable to infer a causal connection, as there was with smoking. Thus, as with research on tobacco smoke, the consistency and quantity of research data on RFR is an important consideration. Here there is sufficient evidence on human exposure, and the results are consistent with laboratory findings—indicating a weight-of-evidence exists. A fact emphasised by the majority of scientists studying RFR.

In its studies on smoking, the EPA concluded that just as *"Lots of smoke produced lots of cancer. Less smoke produced less cancer…The weight of evidence was heavy, indeed."* However, while the EPA termed its findings *"conclusive"* (EPA, 1993), the industry consistently denied and refuted this and challenged the weight-of-evidence approach. Thus the industry's Working Group on Passive Smoking focused on the *"best evidence"* approach from the outset, as it could be gamed to produce the findings in favourable to the industry (Seitz et al., 1989). According to Oreskes and Conway (2011), this approach was heavily biased and involved the strategy of *"excluding studies you don't like and including the ones you do"* with an emphasis on *"ideal research designs."* Thus, the industry categorised what they were doing as *"sound science…and promote[d] the idea that the EPA's work was "junk science.""* To reinforce the *"junk science"* claim in the early 1990s the industry commissioned a reference source called *Bad Science: A Resource Book* report: Its purpose was to guide scientists and journalists to question the findings and integrity of peer-reviewed science (Oreskes and Conway, 2011). The Bad Science resource incorporated the successful strategies and playbooks of conservative scientists and journalists sympathetic to laissez-faire ideology and main-stream business philosophies. Ultimately, as Oreskes and Conway (2011) point out: *"The goal wasn't to correct scientific mistakes and place regulation on a better footing. It was to undermine regulation by challenging the scientific foundation on which it would be built. It was to pretend that you wanted sound science when really you wanted no science at all—or at least no science that got in your way."* This was an important adjunct to the pan-industry approach to the abuse of the scientific method and statistical techniques, which were by now well-known to industry scientists across several fields, including the telecommunications industry, and conduct *"bad science"*.

Elsewhere in this review, the *"constructive dismissal"* approach adopted by ICNIRP and related industry scientists was argued to exclude studies that demonstrated non-thermal effects and include those that did not, and apply impractical, unattainable and non-standard "ideal research designs." Thus, the tried and tested methods of other industries whose products were known to be injurious to public health were increasingly employed by scientists active in ICNIRP and on WHO committees—their attempted dismissal of the NTP and Ramazzini studies stands testament to this.

Additional insights into the method of the constructive dismissal of valid science

We have noted that good science is plagued by valid scepticism, critical rationalism, and concerns about scientific rigour. This is important as correlations between exposures and outcomes may occur by chance or be subject to confounding factors: Thus scientists wish to avoid both *false positives* and *false negatives*. This is compounded by a natural bias among scientists towards measured conclusions. When caught between the *Scylla* of a false positive and the *Charybdis* of false negatives, scientists lean towards approaches that eliminate the former at the expense of the latter. Michaels (2008) points out that *"The nature of epidemiology and the ground rules epidemiologists use ensure that it is far more difficult to find a false positive result than a false negative one."* This is a significant point when considering how the telecommunications industry and the ICNIRP consider that 62% of peer-reviewed studies that find non-thermal effects are actually reporting a false positive. Michaels also states that *"Generally speaking, a poorly conducted study is more likely to result in a false negative (that is, it fails to find a risk increase that is actually present) than in a false positive (mistakenly identifying an excess risk when none in fact exists)."*

Industry funded-science aims to demonstrate negative outcomes—that is, is no evidence of non-thermal effects from exposure from RFR. Michaels (ibid.) holds that *"For the results from a negative study to be taken seriously, the study must be large and sensitive and gather accurate*

exposure data." Elsewhere in this report evidence is adduced that questions the validity and reliability of negative studies on exposures to RFR and human health for such reasons.

Industry and ICNIRP scientists regularly conduct reviews and meta-analyses of extant research on particular exposure-outcomes in response to mounting evidence of non-thermal effects. A review may be qualitative or quantitative and its purpose is to summarise and catalogue the main themes, findings, and conclusions of a body of research. A meta-analysis integrates the results of several well-designed small-scale studies so that exposure-outcome relationships have more statistical power or clarity. Both are open to treatment by industry *junk scientists*. Huber (1993) provides a concise definition of *"Junk science"*: He asserts that it *"is the mirror image of real science, with much of the same form but none of the substance…. It is a hodgepodge of biased data, spurious inference, and logical legerdemain…. It is a catalog of every conceivable kind of error: data dredging, wishful thinking, truculent dogmatism, and, now and again, outright fraud."* Conducting a one-sided, biased review is relatively easy, as the ICNIRP Guidelines and committee reports indicate. A "junk science" meta-analysis is also relatively straight forward: Michaels (2008) points out that *"Build a meta-analysis with flawed studies, and you get a flawed result. In fact, this is a time-honored recipe for countering the results of a well-conducted study: Just mix this good study with several weak or badly designed ones, and you will get a "no findings" conclusion. The added value of this charade is that the investigator and sponsor can claim that the new meta-analysis includes the entire literature and therefore trumps the result of that one pesky study."* This reflects accurately extant practice by junk scientists who wish to create uncertainty and doubt about valid sound scientific findings.

Whether it is an epidemiological or laboratory research study, a review or meta-analysis, Michaels (2008) points out that *"It is relatively easy to design a study or reanalyze someone else's data in a way that ensures that the new study will find no association between the exposure and the disease in question. The joke about "lies, damned lies, and statistics" definitely pertains. The battle for the integrity of science is rooted in issues of methodology."* There are other tools at the junk scientist's disposal. Take for example animal studies. Both the tobacco industry and latterly the telecoms industry manufacture doubt in policymakers and the public by pointing out that the findings of animal studies do not apply to humans. They know full well that human studies are not possible as it is unethical to deliberately expose humans to known or unknown risks to their health. They also obscure the fact that the life sciences depend on animal studies to perform a risk assessment on human exposures to toxins, carcinogens, and other harmful substances placed on the market or into the environment. Michaels (2018) points out that animal studies are a complement to epidemiology: *"For more than a century now, scientists have been exposing animals—especially mammals—to toxic products to predict what will happen when humans are exposed to the same substances. The logic behind these toxicology studies is simple: All mammals have similar tissues, organs, and biochemical systems. For the most part, bad news for a lab rat is bad news for all other mammals, including us. Animals studies can help explain the results of the "natural experiments" that epidemiologists study. They can also predict whether substances that we cannot study epidemiologically might cause cancer in humans."* Unlike sound or good scientists, junk scientists are quick to dismiss (constructively or otherwise) animal studies. Unfortunately, they have convinced the judiciary and the press to do likewise (Michaels, 2008). This is understandable but regrettable as animal studies are an important tool in arriving at scientific truth. The same should apply in the search for truth and justice in the courtroom.

Taking the EPA's findings on secondhand smoke, for example, to test if a correlation in human exposure to secondhand smoke is causal (true positive) or coincidental (false positive), scientists can conduct rigorous experiments to expose animals in controlled studies. As Oreskes and Conway (2011) argued *"If the animals show the same effect, and if that effect follows a dose-*

response curve, then the effect is probably not a coincidence. This is what the EPA now argued for." It is also significant that while several studies may be required to support a theory of no harm, it takes just one showing harm to falsify the theory. We have cited numerous epidemiological studies herein that posited exposure to low-levels of RFR causes cancer. We have also cited numerous rigorous animal studies that find the same effect and that exposures producing negative effects follow a dose-response relationship. As with secondhand smoke, there is only one logical conclusion. But as with the tobacco industry before, the telecommunications and technology sectors have, through their academic supporters and the ICNIRP, attempted to undermine and discredit what is rigorous and relevant research. There are, however, other issues that characterise "bad science" showing no-effects.

On the fallacy of the thermal threshold effect in RFR

As with the tobacco industry the telecommunications and technology sector is misusing the old saying that *"it's the dose makes the poison"*. An example will illustrate how. In the decades following the atomic bomb explosions, not all Japanese citizens exposed to ionizing radiation developed cancer. And so the false theory of the *"threshold effect"* has born. As Michaels (2008) recounts: *"With the exception of a small group of wacky scientists who believe that small doses are good for us, most scientists who are familiar with the studies on the ability of ionizing radiation to cause cancer subscribe to the "linear, no threshold" theory. This theory holds that there is no safe level or threshold for radiation, and that cancer risk increases with exposure in a linear fashion, so twice as much exposure doubles the risk."* With little understanding of how the effects of confounding factors, such as genetic predisposition and so on, industry scientists assume that there is a threshold at which all carcinogens like tobacco smoke and, more recently, RFR, do not apply. However, as argued elsewhere herein, genetics and other biological dispositions mean that the threshold theory is refuted, bot only for carcinogens, and is merely a convenient tool for bad scientists to manipulate sound science (Michaels, 2008, 2009; Markowitz and Rosner, 2013; Oreskes and Conway, 2011).

Thus, it comes as no surprise to find that the threshold theory was employed *"by all sorts of people to defend all sorts of hazardous materials"* (Oreskes and Conway, 2011). This was and still is an error, as the theory is argued to apply only to natural hazards at an evolutionary timescale and not man-made biological hazards within the life of individual humans. Take, for example, microbiologist Emil Mrak who, on behalf of business interests, questioned the posited dangers of various man-made chemical toxins and carcinogens. He used the threshold theory to defend their use in the environment and to claim that merely reducing exposures it would minimise or eliminate the risk to humans. His arguments helped support the tobacco industry and he held that if this view was not accepted, then every manufactured chemical that was proven to pose a risk to human health would be banned. The tobacco industry pivoted on this point and extended his line of thinking to claim that if *"everything from crossing the street to riding a bicycle was harmful, so tobacco should be viewed as just one of the routine risks that people accept by living life. The menace of daily life, some industry apologists called it. Life is dangerous. So is tobacco. Get used to it"* (Oreskes and Conway, 2011). Thus, as with the threshold of the FCC and ICNIRP thermal effects of RFR, the tobacco industry argued that there was a threshold below which its carcinogen and environmental toxin had no effect. However, as Oreskes and Conway (ibid.) argue *"There's also a world of difference between the idea that evolution has equipped humans with some immunity to natural hazards and the idea that we somehow have immunity to something we'd never been exposed to in two million years of evolution."* Logically RFR falls into this category and the thermal effects threshold of RFR power

densities of 10 W/m^2 or 20 W/m^2 as posited by the FCC and ICNIRP respectively is simply spurious.

When cancer is not the only exposure outcome

In *Uncertain Hazards* Tesh (2018) argues that as epidemiological studies tend to focus on specific outcomes such as cancers, where exposures to probable or possible carcinogens is concerned, they fail to capture the full range of possible biological outcomes, such as neurological or reproductive effects suffered by those at risk. Then there is the fact that with many environmental toxins or carcinogens not all members of a population will be equally affected by or at the same levels of exposure, or indeed at any level of exposure at all. As Markowitz and Rosner (2013) point out *"In the absence of extraordinarily sophisticated and extremely expensive longitudinal studies, there is little chance that any but the most unambiguous and obvious problems will be uncovered."* Furthermore, they point out that *"when the dose is low, the response is typically small, and therefore hard to detect. However, all of these limitations could be addressed through the weight-of-evidence approach: no one study is perfect, but each can contribute useful information"* (cf. Oreskes and Conway, 2011). These epidemiological facts are well-known but conveniently ignored by ICNIRP, the FDA, and FCC.

Markowitz and Rosner (2013) also point to *"studies of workers exposed to very low levels of vinyl chloride monomer (VCM) provide hope that other branches of science may have something to add to the environmental debates."* They (ibid.) cite research by Dr. Paul Brandt-Rauf of Columbia University who reports that workers exposed to *"VCM below the current permissible exposure limits develop "specific mutations in the ras oncogene and the p53 tumor suppressor gene…the authors suggest that biomarkers may prove extremely useful "for monitoring human exposures to occupational and environmental carcinogens." The use of such biomarkers may mean that we may not have to wait for epidemiological proof of the effects of chemicals in terms of human disease, but rather "biomarkers can provide intermediary evidence for potential hazardous (or protective) exposure levels that can enhance risk assessment for occupational and environmental exposures and better inform regulatory decisions."* There are parallels with biological outcomes observed in RFR exposures in animals and humans. Hence, there is a strong case for RFR research that examines an increase in oxidative stress and the presence of biological mechanisms that are precursors of diseases using a range of biomarkers identified in extant research (cf. Belpomme et al. 20; 15; Belyaev et al., 2016Miller et al. 2018; BioInitiative Working Group 2012).

Why the ICNIRP et al.'s bad science and constructive dismissal approaches are untenable

In Wendy Wagner's (2003) article *The "Bad Science" Fiction: Reclaiming the Debate over the Role of Science in Public Health and Environmental Regulation* she argues for a set of *transparent* "*concrete inclusion and rebuttal criteria would provide fairer and more consistent regulatory outcomes. Without clear guidelines, agency staff enjoy nearly complete discretion in promulgating protective standards and other regulations. The resulting standards sometimes deviate from statutory goals or administration policy in ways that escape notice. Second, clarifying the inclusion and rebuttal criteria would help focus the issues for judicial review and ultimately reduce the variability in the outcome of such review."* The recent FDA Center for Devices and Radiological Health (CDRH) Report: *Review of Published Literature between 2008 and 2018 of Relevance to Radiofrequency Radiation and Cancer* clearly demonstrates the paucity of inclusion and rebuttal criteria employed by federal agencies and the ICNIRP. In arriving at its conclusions, the unnamed FDA researchers did not adopt the weight-of-evidence approach

favoured by the EPA: instead, the report could have been authored by ICNIRP scientists, as it appeared to follow the same approach evident in the ICNIRP (1998, 2020) Guidelines viz. excluding robust, valid and reliable peer-reviewed studies on spurious grounds.

This report has adduced evidence that as of 2017 68% of 2,653 peer-reviewed scientific research studies in PubMED and related databases found physical and biological evidence of non-thermal effects to RFR exposures, while only 32% of studies found no evidence of effects (see Bandara and Carpenter, 2018). How then could the ICNIRP (or indeed the FDA) exclude this significant body of laboratory and epidemiological research?

"Bad science" and *"junk science"* are synonyms (see Huber's definition above). Thus, bad science is often fraudulent: that is, data informing the findings and conclusions will have been invented, mis-represented, and/or manipulated. Such data may also have been cherry-picked, with important data deliberately omitted. Alternatively, data may be presented in such a fashion that makes it difficult for a reviewer to understand the steps that were taken to gather or produce and analyze the data. Bad science depends on obfuscation, manipulation, and opacity on population or data samples that are unrepresentative. In bad science findings and conclusions are typically based on insufficient or inconsistent data (Oreskes and Conway, 2011; Goldacre, 2015). The extant body of research on non-thermal effects generally presents none of these weaknesses, while the reviews conducted by ICNIRP consistently exclude, misinterpret, or misrepresent data from original peer-reviewed studies.

Scientific peer review is the first line of defence in dealing with bad science. Scientific claims from empirical studies or reviews typically undergo blind review and assessment by experts in the field before they are considered valid. At base, a study's internal and external validity and reliability will be assessed by reviewers (Hoffmann et al., 2017). A study's research design will receive initial interest from peer-reviewers, particularly the data gathering and analysis techniques employed and the subsequent approach to data interpretation. At a more granular level reviewers examine the quality and quantity of data, and especially the statistical techniques employed by the researchers to demonstrate cause and effect and identify true positives and avoid false positives. Finally, the reasoning behind inferences drawn and recommendations made will be analysed. This is a lengthy and highly intensive process that may result in a paper going through several rounds of review, spanning months if not years, before a unanimous accept decision to publish is made. If the journal editor is unhappy, he/she may refer the manuscript for further review to additional experts. Such is the completion for publication slots is that the acceptance rate for top-ranked journals is typically low and the standards high. Most papers are rejected as peer-reviewers are tough to convince, being natural sceptics. Again, consider the 68% of peer-reviewed journal articles finding physical and biological effects of RFR.

We return to the EPA example of exposure to second hand smoke and cancer to illustrate the power of the peer-review process and the conservative nature of independent good science, as opposed to industry-oriented *"bad science."* Oreskes and Conway (2011) report that the peer-reviewers of the EPA report on second-hand smoke requested further discussion on the existence of the uncertainties and confounding effects. Why? *"Their major concern was that the report had understated the risks. Its conclusions were not too strong, but too weak."* As they (ibid.) state: *"How do you judge epidemiological evidence when there's only a modest effect? You judge it in light of what else you know about the issue."* While the epidemiology was weak, research had previously shown that *"smoking causes cancer, and that passive smoking introduces the same toxins into the lungs…So even if the statistical effects were modest, there was good reason to believe that they were real. The reviewers wanted the EPA panel to make this explicit, "with each step in the argument … carefully addressed.""* The reviewers also found the EPA report too weak

on its findings on the effect of second-hand smoke on children viz. *"the evidence for respiratory health effects in children [is] stronger and more persuasive"* in the report than stated, and of greater significance to public health. The report went through two review cycles with the conclusions and implications for public health being strengthened each time with cigarette smoke being classified as a Class A carcinogen. The reviewers did not apply a *"constructive dismissal"* of the EPA study—they did not question the 90% confidence level, nor the *"totality of evidence,"* nor did they indicate that a *"threshold effect"* was in operation.

Compare this with the ICNIRP review of the NTP (2018a,b) study of RFR and cancer following its final publication in 2018. That study was also peer-reviewed by a panel including former ICNIRP members. Neither, the internal nor external validity nor reliability of the study was called into question by the peer review panel. However, it did find that like the EPA report 25 years earlier, the interpretation of its findings needs to be strengthened along with its conclusions and recommendations. Remember, the peer-review panel were selected for their specific field-level expertise, unlike the ICNIRP reviewers of the 1998 and 2020 Guidelines. This raises a significant question mark over the motivation of the ICNIRP. The NTP study provided strong, independent evidence to support a cause-and-effect relationship between RFR exposure and cancers. RFR was shown to interfere with cell function in the laboratory rats in the experiment. There was *"clear evidence"* of this cause-effect relationship. This coupled with similar findings in the Ramazzini Institute study and many others indicate a "weight-of-evidence" that is difficult to refute.

Michaels (2008) states: *"In the end, public health and environmental protections are based not on the results of individual epidemiological or animal studies but rather on an interpretation or synthesis of the findings of multiple studies and multiple types of studies. Using their best judgment in interpreting these studies and other data, experts look for the weig\ht of the evidence. They carefully examine and attempt to synthesize the entire picture, then make a pronouncement about causation or risk based primarily on the studies to which they have accorded more weight, perhaps because they are of better quality or are more numerous or simply more convincing."* This process is open to abuse through bad science and by bad scientists. Given the weight of the evidence adduced herein, it is reasonable to conclude that the industry and its agents, such as ICNIRP scientists, are engaging in *bad science,* while independent studies are valid, reliable, and trustworthy and represent *good science.* However, bad science currently holds sway due to the influence of the industry and the duplicity of ICNIRP experts. The consequence of all this is that regulators, policymakers, the judiciary, and the public are, in Sir Karl Popper's terms, *"being led by the nose".*

Distorting good science to introduce doubt and falsehoods: An Example

From the 1950s a distortion of the difference between ionizing and non-ionizing radiation has been used to undermine the existence of non-thermal effects, particularly occupational cancers in the military or industry. Respected scientists and journalists have been discrediting good science with *"bad"* or *"junk science"* (cf. Goldacre, 2014; Michaels, 2008). This has been the case in several critical peer-reviews of ICNIRP Guidelines and reports, in addition to those such as the WHO, the EU's Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), and the UK's Advisory Group on Non-ionising Radiation (AGNIR)) where members of the ICNIRP engaged in *"constructive dismissal"* and the misapplication of the scientific method or the Bradford Hill Guidelines, (see: Cherry, 2000, 2004; Adlkofer, 2015; Sage et al., 2016; Starkey, 2016; Hardell, 2017; Carlberg and Hardell, 2017; Pockett, 2019; Hardell and Nyberg, 2020; Melnick, 2020).

In the case of EMF, *"physics used in an improper manner may mislead to wrong conclusions"* (Vistnes and Gjötterud, 2001). Here the physical properties of photons, i.e. they are small energy packages that possibly deliver enough energy so that chemical bonds may be broken and molecules ionized, mean that in human cells exposed to ionizing radiation such as x-rays, may result in single or double-strand DNA breaks and ultimately in the cell becoming cancerous. Thus, ionizing radiation which occurs at frequencies at and above ultraviolet (UV) light is ionizing radiation. A simple equation demonstrates the difference in frequency-dependent energy levels: *"individual photons have an energy E given by the famous equation E = hv, where h is Planck's constant and v is the frequency of the "radiation.""* (Ibid.). While UV-B has sufficient energy to cause DNA breaks, UV-A does not: however, UV-A, while a form of nonionizing radiation, damages DNA through alternative mechanisms (Rastogi et al., 2010). Through complex cellular mechanisms, UV-A generates free radicals or *"reactive oxygen species (ROS) and induces oxidative DNA damage"* thereby increasing cancer risk (Brem et al. 2017). RFR is non-ionizing microwave radiation and research has demonstrated that it too causes an increase in ROS and oxidative stress in cells using sophisticated mechanisms also explained by classical physics (see Barnes and Greenebaum, 2015, 2020). Thus, Panagopoulos (2018) states that *"there is no evidence that the environmentally accounted microwave radiation types (as those used in modern telecommunications) transmitted by antennas, radars, satellites, etc. consist of photons."* Consequently, *"radio frequency fields should be treated as classical electromagnetic fields rather than as field quanta. Classical electromagnetism can handle the difference between "near-field" and "far-field" and the difference between static fields and time varying fields"* (Vistnes and Gjötterud, 2001). The problem here is that the industry and its scientists have been misusing and abusing scientific theory and empirical facts to suit their arguments.

A recent paper by David Grimes with co-author Dorothy Bishop is a case in point. The purpose of the Grimes and Bishop (2018) paper was to dispute valid research presented by Sage and Burgio (2017) in the journal *Child Development*. Here, Grimes and Bishop claim that Sage and Burgio possess *"a fundamental misunderstanding of radiation physics…the assertion by the authors that DNA damage can be induced by RF waves makes no sense— microwave radiation is strictly nonionizing, lacking sufficient energy to eject electrons and far below the threshold energy to do so. This can be easily seen by comparison with visible light, another nonionizing EMR type."* They conclude with lofty sermonizing viz. that the authors' claims should have been better *"informed and objective, rather than polemics based on cherry-picked information dressed up in impressive-sounding technical language without have conducted a thorough examination of extant research."* Elsewhere, in an Observer article, Grimes (2018) erroneously points out *"RF (and indeed, visible light) are notoriously low energy and non-ionising, lacking the ability to wreak havoc on DNA. For cancers to form, a carcinogen needs to damage DNA – unless some extremely novel mechanism were to be discovered, it is extraordinarily unlikely that RF could cause cancer."* Thus, a flawed thesis is posited to discredit valid findings. Unfortunately, Dr. Grimes (2018) efforts at "constructive dismissal" do not end here. Grimes claims *"To ignore strong evidence against a conjecture while inflating weak studies is textbook cherry-picking, where data that might contradict a particular hypothesis is jettisoned, and only evidence fitting the desired story retained. This is antithetical to science, where the totality of evidence must be assessed in concert."* He is referring to a news article by Hertsgaard and Dowie (2018b) titled *"The inconvenient truth about cancer and mobile phones."* The studies Dr. Grimes cites in making his claims are referenced herein. However, he is guilty of his claim of "*textbook cherry-picking"* as he ignores the 68% of studies that find effects, indeed he misrepresents the findings of the Interphone Study. In the peer-reviewed publication of that study, Cardis et al. (2011) conclude: *"There were suggestions of an increased risk of glioma in long-term mobile phone users with high RF exposure and of similar, but apparently much smaller, increases in meningioma risk."* In

Grimes' (2018) article he claims *"there was no causal relationship between phone use and brain tumours. And while one would expect cancer rates to increase with usage were this a cause, the dose-response curve betrayed no signs of correlation."* In a follow-up study of the Canadian Cohort in 2017, Momoli et al. (2017) found a significant increase in glioma: *"For glioma, when comparing those in the highest quartile of use (>558 lifetime hours) to those who were not regular users, the odds ratio was 2.0 (95%confidence interval: 1.2, 3.4). After adjustment for selection and recall biases, the odds ratio was 2.2 (95% limits: 1.3, 4.1)."* The Danish Cohort Study (Schüz et al. 2009) cited by Dr. Grimes has been heavily criticized for its underestimation of the risk of RFR from cell phone exposure due to its exclusion of the most frequent users—over 200,000 business users: nor did it capture individual exposure data; and most importantly there are no controls or independent data on cellphone subscription (Söderqvist et al., 2012[17]). In an overall context, a recent review of 24 epidemiological case-controlled studies, which would have been available at the time the Observer published the article by Grimes, demonstrated an increased risk of gliomas and other brain tumours with long-term exposure to RFR from mobile phones (Bortkiewicz, Gadzicka, and Szymczak, 2017: cf. Table 5 in Vienne-Jumeau et al. 2019). Thus, there is a discrepancy between what the authors of the Interphone study conclude, in addition to the conclusions of the authors of other peer-reviewed research, and the arguments presented by Dr. Grimes, which clearly favour the industry position, and fail to acknowledge the weight-of-evidence that falsifies his claims.

Additional evidence on how the ICNIRP and its fellow-travelers manipulate science and research

According to the latest ICNIRP Guidelines (2020, p. 3): *"Radiofrequency EMFs [i.e. RFR] consist of oscillating electric and magnetic fields; the number of oscillations per second is referred to as "frequency," and is described in units of hertz (Hz). As the field propagates away from a source, it transfers power from its source, described in units of watt (W), which is equivalent to joule (J, a measure of energy) per unit of time (t). When the field impacts upon material, it interacts with the atoms and molecules in that material. When a biological body is exposed to radiofrequency EMFs, some of the power is reflected away from the body, and some is absorbed by it. This results in complex patterns of electromagnetic fields inside the body that are heavily dependent on the EMF characteristics as well as the physical properties and dimensions of the body. The main component of the radiofrequency EMF that affects the body is the electric field. Electric fields inside the body are referred to as induced electric fields (Eind, measured in volt per meter; V m−1), and they can affect the body in different ways that are potentially relevant to health."* This explanation does not reference the ionizing vs. nonionizing photon thesis from quantum physics, rather it is based on theories in classical physics. Following Vistnes and Gjötterud (2001), Barnes and Greenebaum (2015, 2020), and Panagopoulos (2018), ICNIRP holds that *"induced electric fields" "can affect the body in different ways"* with health effects. The issue here is that neither certain ICNIRP members nor scientists holding the thermal effects only position, appear to acknowledge the core principles on which their own guidelines are based.

Thus, instead of investigating the ways in which RFR "*affects the body in different ways that are potentially relevant to health"* it systematically discredits ALL studies that show non-thermal effects and favours those that do not. The Grimes (2018) case cited above provides just one example of this, which is not surprising given the influence of the ICNIRP on researchers. Again, this is 'normal' practice in science communities (Kuhn, 2012). The most recent examples of

[17] https://electromagnetichealth.org/electromagnetic-health-blog/critical-comments-danish-study/

ICNIRP practice come from its *"constructive dismissal"* of the NTP (2018a,b) and Ramazzini Institute studies (Falcioni et al., 2018). The NTP's Dr. Ron Melnick stated that the National Toxicology Program (NTP) study on radio frequency radiation (RFR) *"was designed to test the (null) hypothesis that cell phone radiation at non-thermal exposure intensities could not cause adverse health effects, and to provide dose-response data for any detected toxic or carcinogenic effects"* (Melnick, 2019). He states unequivocally that the null hypothesis has been falsified in a Popperian sense, and the link with cancer proven beyond all doubt. In their analysis of previous human epidemiological studies with the findings of the NTP research, Swedish scientist oncologists Lennart Hardell and Michael Carlberg (2019) *"conclude that there is clear evidence that RF radiation is a human carcinogen, causing glioma and vestibular schwannoma (acoustic neuroma). There is some evidence of an increased risk of developing thyroid cancer, and clear evidence that RF radiation is a multi-site carcinogen."* The scientific significance is unequivocal and proves without a shadow of a doubt that the black swans of non-thermal effects are very real indeed.

The industry and ICNIRP scientists set out to implement what Cherry (2004) called *"constructive dismissal"* techniques aimed at dismissing the findings of epidemiological and experimental findings. These include the following:

- *"Thermal only view is the consensus of scientists who find only thermal effects: This implies any research showing non-thermal effects is unscientific.*
- *Applying quantum physics explanations of ionizing radiation to non-ionizing radiation.*
- *Strict adherence to the replication principle ignoring the fact that it is easier to replicate a no-effect study, as opposed to an effect study.*
- *The scientific method holds that each study is evidence, particularly those that have good reliability, internal and external validity and which have been peer-reviewed.*
- *Misapplication of the Bradford Hill Viewpoints to dismiss studies.*
- *Citing studies are either too small or which fail to capture the long latency of cancer.*
- *Distorting the findings or studies that show significant increases in cancer as showing no evidence of increase.*
- *Quoting conservatively-worded conclusions in papers (as per normal science) that state no-effects were evident, and ignoring the data and statistical analyses that demonstrate clear effects and dose-response relationships.*
- *Criticizing or dismissing epidemiological studies on the grounds of alleged poor definition of populations and exposures, despite extensive peer-reviews and the inclusion of data in meta-analyses.*
- *Cherry-picking flaws that undermine the overall or collective findings."*

Following the IARC classification of RFR as a possible carcinogen, ICNIRP members and scientists Swerdlow et al. (2011) asserted that *"Methodological deficits limit the conclusions that can be drawn from the Interphone study, but its results, along with those from other epidemiologic, biological, and animal studies and brain tumor incidence trends, suggest that within about 10–15 years after first use of mobile phones there is unlikely to be a material increase in the risk of brain tumors in adults. Data for childhood tumors and for periods beyond 15 years are currently lacking."* The overall approach in their paper broadly follows the above techniques. They concluded that *"Although there remains some uncertainty, the trend in the accumulating evidence is increasingly against the hypothesis that mobile phone use can cause brain tumors in adults."* This is demonstrably false, given the IARC classification and the earlier EPA classification of RFR as a possible carcinogen.

The NTP study is the subject of critical evaluation in ICNIRP Notes (2018, 2020). It follows the *"constructive dismissal"* approach to the letter and ignores the fact that the NTP study was subject to extensive peer-review between 2016 and 2018, including former ICNIRP scientist Prof. J.C. Lin. Prof. Lin is Professor Emeritus of electrical engineering, bioengineering, physiology, and biophysics at the University of Illinois, Chicago. He was a long-standing member of ICNIRP (2004-2016). He was invited by the National Institute of Environmental Health Sciences (NIEHS) with 13 scientists (10 pathologists and toxicologists, 2 electrical engineers, and 1 biostatistician) to carry out a peer-review of the NTP draft reports on cancer development through RFR. Subsequently, he published several papers, the first in 2018 titled: *Clear evidence of cell phone RF radiation cancer risk* (Lin, 2018). This view stands at odds with that of his former colleagues.

In his response to the ICNIRP Notes, NTP scientist Dr. Ron Melnick (2020) states the ICNIRP *"made several incorrect statements that appear to be written to justify retaining exposure standards that were established 20 years ago."* The ICNIRP (2020) acknowledge the problems that would have arisen had its scientist accepted the NTP and Ramazzini findings: *"…if the research was shown to have relevance to humans, this would represent a crucial issue for ICNIRP to incorporate into the advice and guidance that it provides to the community…such as its RF EMF exposure guidelines."* Melnick (2020; cf. 2019) focuses on *"correcting ICNIRP's false claims about the methodology, interpretation and relevance"* of the NTP (2018a,b) studies. Melnick states unequivocally that the *"ICNIRP wrongly claims that methodological issues "preclude drawing conclusions about carcinogenicity" from the NTP studies on RF radiation."* In response to criticism regarding the pathology aspects Melnick points out that *"for all NTP studies, an independent quality assessment pathologist (second tier) reviews all lesions identified by laboratory pathologist…with reviews by working groups (third tier involving over 30 pathologists)."* These were blind reviews. Melnick adds that "the assertion by the ICNIRP, which has never been made in the 40-y existence of the NTP, impugns the validity of all 600 bioassays performed by this program." He then points out that all original slides and data are available. Overall Melnick holds that the ICNIRP provides *"an inaccurate portrayal and interpretation of the data"* and statistical approaches. Specifically, the following points were made by Dr. Melnick in response:

1. "The ICNIRP incorrectly states that *"the NTP reports have not yet undergone full peer–review"* as the NTP studies underwent multiple peer reviews, including an unprecedented 3-day independent review in March 2018.

2. Contrary to the ICNIRP all of the endpoints presented in the NTP reports were specified a priori.

3. ICNIRP misrepresents or excludes key conclusions from the NTP studies.

4. ICNIRP incorrectly states that animals in the NTP study were exposed *"over the whole of their lives."*

5. ICNIRP incorrectly criticises the exposure intensities used in the NTP studies as being *"75 times higher than the whole-body exposure limit for the general public"* : this matter has been explained in full in Melnick (2019) viz.

"While the exposure limit to RFR for the general population in the US is 0.08 W/kg averaged over the whole body, the localized exposure limit is 1.6 W/kg averaged over any one gram of tissue (FCC, 1997); for occupational exposures, the limit is five times higher (0.4 W/kg

and 8 W/kg, respectively). Thus, the whole-body exposure levels in the NTP study were higher than the FCC's whole-body exposure limits (3.8 to 15 times higher than the occupational whole-body exposure limit). Whole-body SAR, however, provides little information about organ-specific exposure levels (IARC, 2013). When an individual uses a cell phone and holds it next to his or her head, body tissues located nearest to the cell phone antenna receive much higher exposures than parts of the body that are located distant from the antenna. Consequently, the localized exposure level is more important for understanding and assessing human health risks from cell phone RFR. When considering organ-specific risk (e.g., risk to the brain) from cell phone RFR, the important measure of potential human exposure is the local SAR value of 1.6 W/kg (the FCC's SAR limit for portable RF transmitters in the US, FCC 1997) averaged over any gram of tissue. In the NTP study in which animals were exposed to whole-body RFR at SARs of 1.5, 3, and 6.0 W/kg, exposures in the brain were within 10% of the whole-body exposure levels. Consider the converse scenario. If the brain and whole-body exposures were limited to 0.08 W/kg, then localized exposures in humans from use of cell phones held next to the ear could be 20 times greater than exposures to the brain of rats in the NTP study. Under this condition, a negative study would be uninformative for evaluating organ-specific human health risks associated with exposure to RFR. Therefore, exposure intensities in the brains of rats in the NTP study were similar to or only slightly higher than potential, localized human exposures resulting from cell phones held next to the head, and lower than the FCC's permissible localized limit for occupational exposures."

6. ICNIRP falsely claims that whole-body exposures in the NTP produces immediate adverse effects. Melnick points out that *"the animals tolerated the exposure levels used in the NTP study without significant effects on body temperature, body weights, or induction of tissue damage"* (NTP 2018a, 2018b). Other arguments demonstrated the patently inaccurate and misleading ICNIRP arguments.

7. ICNIRP of the consistency between the NTP (2018a) and the Ramazzini study (Falcioni et al., 2018) is argued to be disingenuous. The studies were clearly independent and the fact that *"both found increased incidences of heart schwannomas and Schwann cell hyperplasias in Sprague-Dawley rats under different exposure environments and different RF intensity levels is remarkable."* Other than that they were not attempts at replication and it would be *"unreasonable to expect a linear dose-response by combining data from these two separate studies."*

8. ICNIRP misrepresents the findings of the NTP study using research dated from 1991. However, Melnick points out that it *"lends further credibility"* to *"the increased incidences of schwannomas in exposed rats being due to the exposures to cell phone RFR."*

9. ICNIRP cherry-picks two reviews that show *"no association between RFR and acoustic neuromas, while ignoring any mention of the IARC monograph that reported positive associations between RFR from cell phone and glioma and acoustic neuroma in humans."*

10. ICNIRP criticises the paucity of cardiac schwannomas in control male rats. Melnick (2019) states:
    "Gliomas and schwannomas of the heart are uncommon tumors that occur rarely in control Sprague-Dawley rats. It is not unusual to observe a zero incidence of uncommon tumors in groups of 50-90 control rats. In experimental carcinogenicity studies, the most important control group is the concurrent control group. As mentioned above, the uniquely

designed reverberation chambers used in the NTP study were fully shielded from external EMFs, and the lighting source was incandescent instead of fluorescent light bulbs. The housing of rats in the RFR shielded reverberation chambers could affect tumor rates in control animals. No data are available on expected tumor rates in control rats of the same strain (Hsd: Sprague Dawley rats) held under these specific environmental conditions. Thus, historical control data from previous NTP studies are not reliably informative for comparison to the results obtained in the cell phone RFR study."

11. ICNIRP presents hypothetical arguments instead of staying with the experimental data *"to downplay the significance of a true response."*

12. ICNIRP documented inaccurate portrayals, interpretations and comments on survival differences between animal controls and exposure groups which were addressed in Melnick (2019).

13. The ICNIRP's requirements for blind pathology to avoid bias in exposure status were addressed in Melnick (2019).

14. ICNIRP's issue with multiple comparisons leading to possible false positives (with a probability of 0.5) was stated by Melnick to have been addressed by the NTP in its release of the partial findings of the RFR study (NTP, 2016). Again such concerns are spurious given the NTP's rigour.

15. The ICNIRP concludes that the NTP's study is not consistent with the RFR cancer. Melnick rightly points out that this is incorrect. In addition, its claim that epidemiological studies have not found evidence for cardiac schwannomas ignores the fact that extant research has not studied the relationship between RFR and the risk of cardiac schwannomas. Melnick notes that the IARC classified RFR as a *"possible human carcinogen" based largely on increased risks of gliomas and acoustic neuromas (which are Schwann cell tumors on the acoustic nerve) among long term users of cell phones. The concordance between rats and humans in cell type affected by RFR is remarkable and strengthens the animal-to-human association."*

Thus, Melnick (2019, 2020) addresses the ICNIRP's misrepresentations, falsehoods, and criticisms forensically on the issues of methodology, interpretation, and relevance of the NTP study. Melnick (2020) rightly asserts that RFR's carcinogenicity aside, the ICNIRP *"neglected to point out that other adverse effects were observed in the NTP studies, including reduced birth weights, DNA strand breaks in brain cells (which is supportive of the cancer findings), increased incidences of proliferative lesions (tumors and hyperplasia) in the prostate gland, and exposure-related increases in the incidence of cardiomyopathy of the right ventricle in male and female rats. In addition, other studies have reported adverse effects on male and female reproduction and neurobehavioral effects resulting from exposure to low-intensity non-ionizing radiation."* To document this would have opened a Pandora's Box for the industry. Melnick (2020) concludes that *"The NTP studies show that the assumption that RF radiation is incapable of causing cancer or other adverse health effects other than by tissue heating is wrong. If ICNIRP's goal is truly aimed at protecting the public from potential harm, then it would be appropriate for this group to quantify the health risks associated with exposure to RF-EMFs and then develop health-protective guidelines for chronic exposures, especially for children, who are likely to be more*

susceptible than adults to adverse effects of RF radiation." He continues, "*At the very least, ICNIRP should promote precautionary advice for the general public rather than trying to justify their decision to dismiss findings of adverse health effects caused by RF-EMFs and thereby retain their 20+ year-old exposure guidelines that are based on protection against thermal effects from acute exposures."*

Thus, based on several deceptive and incorrect assertions, the ICNIRP concludes that both the NTP and Ramazzini studies "*do not provide a reliable basis for revising the existing radiofrequency exposure guidelines."* As per the industry playbooks described in Michaels (2008, 2009), Oreskes, and Conway (2011), and Walker (2017), "doubt is their product." Implementing this playbook is easily achieved as Michaels (2008, 2009) argues that epidemiology is *"a sitting duck for uncertainty campaigns"* (cf. Oreskes, and Conway, 2011). In considering RFR health risks, exposures must be estimated and risks to humans extrapolated from animal studies *in vivo* or cellular studies *in vitro.* Persistent exposure to RFR may cause diseases such as brain cancer or neurodegenerative conditions, but these diseases could also be triggered by other environmental or genetic vectors. As with those from the tobacco, petrochemical, and drug industries, the ICNIRP and industry scientists can easily cast doubt on the assumptions, methods, and findings of independent public health-minded scientists. Furthermore, the telecom industry's strategy for countering public health concerns is proving more successful than its predecessor's as indicated by the findings of research from Harvard Law School. In *Captured Agency*, Harvard Research Fellow Norm Alster (2015) illustrates how the telecommunications industry captured the Federal Communications Commission—the US regulator. Research adduced here indicates the same may apply when it comes to the ICNIRP and its influence over the WHO, AGNIR and PHE (Starkey, 2016; Pockett, 2019)

Is trust in the ICNIRP misplaced?

Independent peer-reviewed research continues to identify significant research deficiencies, omissions, inaccuracies, falsehoods, and distortions in ICNIRP research reviews and guidelines (Adlkofer, 2015; Hardell, 2017; Hardell and Carlberg, 2019; Hardell and Nyberg 2020; Pockett, 2019; Melnick, 2019, 2020): they also question SCENIHR reports, due to the significant participation of ICNIRP commissioners (Starkey, 2016; Belpomme et al. 2018; Pockett, 2019). It is also significant that five of the six core group members responsible for drafting the WHO's Monograph on RF fields were directly affiliated with the ICNIRP NGO (Hardell, 2017). Similarly, the chapter on RFR in the WHO's World Cancer Report 2020 was chiefly authored by ICNIRP member Professor Martin Röösli (see Laurier and Röösli, 2020). Research has demonstrated that the WHO is deficient in managing conflicts of interest (Wang et al., 2019). This is compounded by what many consider the blatant disregard of the ICNIRP for basic ethical principles and its poor management of conflicts of interest: Take for example that Pockett (2019, p. 4) finds the *"ICNIRP is a self-selected, private (non-governmental) organization, populated exclusively by members invited by existing members. The organization is very concerned to project the image that it is composed of disinterested scientists—indeed all ICNIRP members are required to post on the organization's website detailed declarations of interest (DOIs). However, a closer inspection of these DOIs reveals that a good many of the sections of a good many of the forms remain unfilled, and a detailed list of undeclared conflicts of interest among ICNIRP members has been published by a group of concerned citizens. The relevant section of WHO is essentially identical to ICNIRP… in spite of their stated rules and protestations to the contrary, there have been persistent allegations that both ICNIRP and the relevant section of WHO are riddled with undeclared conflicts of interest."* These points echo Starkey's (2016) separate critical analysis of conflicts of interest involving the WHO, ICNIRP, and AGNIR.

However, there is one aspect of the ICNIRP's affairs and conduct that has not received the attention it deserves. Given the worldwide acceptance of the INCIRP and the influence its research and guidelines have on the WHO, governments, regulators, and policymakers generally, it is reasonable to assume that its income and expenditures are significant. The ICNIRP is an NGO that has persistently and consistently denied receiving industry funding. Hence, it declares it has no conflicts of interest at any level. Given the range of its presumed research, investigatory and dissemination activities, the fact that it has 13 sitting commissioners, 25 expert advisors, and presumably office and administration staff, then its income and expenditures must be commensurate with its international standing and influence in shaping public policy on technology and human health. The other standards-making body in this technology area is the IEEE. The published accounts for the IEEE show that in 2018 its revenues stood at $531,942,200. The ICNIRP's Financial Accounts are shown in Appendix B. These are extracts from its Annual Report 2018. Its annual revenues for 2018 are shown as 133.254,20. The currency is not shown, so it is presumed that this is in Euro. Its expenditures are listed at - 150.959,67. So the annual income for this global NGO is €133,254. That is significantly less than the salary of a professor at a top US university. A desktop search found no other international NGO of significance with similar financial accounts. A major question begs as to how the ICNIRP can fund its many activities and deliver high quality, reliable and accurate research outputs and guidelines and disseminate these globally? This is not an insignificant issue as the ICNIRP has not been transparent about its activities nor its income. Every government agency in Europe looks to the ICNIRP for guidelines. How can this organisation do what it claims to do when its income is less than that of a senior civil servant? To have ICNIRP scientists drafting safety guidelines while also acting as members of expert groups responsible for objectively assessing those safety guidelines is anathema to all principles of good governance. It is akin to academics acting as authors and reviewers of their scientific papers. No other area of scientific endeavour would countenance such a conflict of interest or lack of independence.

In a 98 page detailed report on the ICNIRP and its activities, Members of the European Parliament, Michèle Rivasi and Dr. Klaus Buchner find that *"[t]he composition of ICNIRP is very one sided. With only one medically qualified person (but not an expert in wireless radiation) out of a total of 14 scientists in the ICNIRP Commission and also a small minority of members with medical qualifications in the Scientific Expert Group, we can safely say that ICNIRP has been, and is still, dominated by physical scientists. This may not be the wisest composition when your remit is to offer advice on human health and safety to governments around the world."* However, they demonstrate that this makes it easier to ignore or dismiss research from medical and related disciplines. Buchner and Rivasi (2020) observe that ""*a closed circle of like-minded scientists" has turned ICNIRP into a self-indulgent science club, with a lack of bio-medical expertise, as well as a lack of scientific expertise in specific risk assessments. Thereby, creating a situation which might easily lead to "tunnel-vision" in the organisation's scope. Two leading experts, Hans Kromhout and Chris Portier, confirmed to us that ICNIRP is a closed, non-accountable and one-sided organisation."* They (ibid.) report that "*In addition to the fact that certain members of ICNIRP, are simultaneously members of the International Committee on Electromagnetic Safety (ICES) of the US-registered Institute of Electrical and Electronics Engineers (IEEE), we have seen further evidence of a close cooperation between ICNIRP and ICES, an organisation in which many people from the media and telecom industries, as well as from the military, are actively and structurally involved. During the current leadership of ICNIRP, these ties have become even closer "with the goal of setting internationally harmonized safety limits for exposure to electromagnetic fields". This must surely be considered as a situation in which conflicts of interest are a real possibility. It is clear from ICES minutes that ICNIRP worked very closely with IEEE/ICES on the creation of the new RF safety guidelines that were published in March 2020.*

And this implies that large telecom-companies such as Motorola and others, as well as US military, had a direct influence on the ICNIRP guidelines, which are still the basis for EU-policies in this domain." This study provides detailed evidence of a range of conflicts of interests of ICNIRP members, including its current chair.

So successful is the ICNIRP in influencing the EU and governments globally, including the US federal agencies such as the FCC and FDA, that industry lobbying in this area is now practically non-existent, although that was not always the case (Buchner and Rivasi, 2020) viz. the *"European Telecommunications Networks Operators' Association (ETNO) does not lobby for lowering the ICNIRP standards, as these are not seen as part of the "regulatory pressure" that hampers technological development. On the contrary: the norms ICNIRP proposes are the "harmonised limits" that ETNO welcomes. All in all, the telecom-sector seems to be quite pleased with ICNIRP's positioning. This deviates from the standard procedure in EU-policy making, where a specific industry concerned will, on essential aspects, always try to influence laws and regulations in its favour through various lobbying strategies. Apparently, in the case of ICNIRP, there is simply no need to do so. At the same time, the insurance sector does not, at present, seem very reassured and does not want to be put in a situation of having to pay potential litigation costs, if and when telecom companies get sued, something that is happening more and more often."* The same applies to the US, where the industry has captured the FCC (Alster, 2015).

The credibility and integrity of the ICNIRP's position are undermined by former ICNIRP members that now recognise RFR as a significant risk to human health (see Lin, 2019). They find themselves in direct opposition to their former colleagues, particularly where the results of the NTP study is concerned. Because of the over-reliance on what the majority of scientists concerned about human health and wellbeing consider deeply flawed and biased ICNIRP guidelines, PHE and UK policymakers possess a fundamental ignorance of the large body of extant research on the significant non-thermal health effects of RFR (cf. Starkey, 2016). There is an increasing body of evidence in peer-reviewed academic research that confirms governments and policy-makers; (1) may be misled by the ICNIRP (Adlkofer, 2015; Hardell, 2017; Hardell and Carlberg, 2019; Hardell and Nyberg 2020; Pockett, 2019; Melnick, 2019, 2020); (2) are succumbing to pressures from industry and lobbyists (Adlkofer, 2015; Michaels, 2008; Walker, 2017); or (3) are turning a blind eye to scientific and public concerns for economic reasons (Alster, 2015)—which in the UK relate to its digital transformation strategy, lucrative industry licenses, and significant tax revenues.

In an interview with the editor in chief of The Lancet, Richard Horton, Brian Appleyard quotes him as stating that *"The leadership of British science and medicine is in a collusive affair with government, frightened to disengage and criticise in case they lose their place at the political table":* While referencing the behaviour of scientists during Covid-19 emergency, he adds: *"They're supposed to be giving independent advice to the government. But they don't give independent advice. They support government. Our scientific community has become the public relations wing of a government that has abjectly failed to respond to this pandemic"* (Appleyard, 2020). There is a question as to whether this applies to, or is characteristic of, scientists who engage in issues of public health concern in the UK, particularly those involved in AGNIR or SCNEIHR. If so, then, it may be argued that the decision-making process on the introduction of RFR technologies, especially 5G and its implications for public health, maybe deeply flawed.

Are independent scientific studies more trustworthy?

It is an interesting fact that independent scientific studies are two and a half times more likely to find evidence of biological effects and health risks than industry-funded studies (Huss et al., 2006; Prasad et al., 2018; Leach et al., 2018). It is also generally agreed that independent studies have greater scientific validity and are better executed (Michaels, 2008), due, perhaps, to the absence of conflicts of interest. Furthermore, Dr. Henry Lai, Professor Emeritus at the University of Washington, reports that all studies conducted between 1990 and 2017 found significant health risks such as DNA damage (64%), neurological effects (72%), and oxidative stress (90%).[18] These percentages of effects and risks are mirrored in a recent analysis of thousands of research papers in which 68% of peer-reviewed scientific research studies found physical and biological non-thermal effects, while only 32% of studies, found no evidence of effects (Leach et al., 2018). Research cited therein indicates that the weight of objective scientific evidence has always indicated significant risks to human health—these risks are magnified significantly where children are concerned.

In 2012, Dr. Ben Goldacre published *Bad Pharma*. In an evidence-based treatise on the pharmaceutical industry, Goldacre concluded: *"Drugs are tested by the people who manufacture them, in poorly designed trials, on hopelessly small numbers of weird, unrepresentative patients, and analysed using techniques which are flawed by design, in such a way that they exaggerate the benefits of treatments. Unsurprisingly, these trials tend to produce results that favour the manufacturer…Medicine is broken ... We like to imagine that medicine is based on evidence, and the results of fair tests. In reality, those tests are often profoundly flawed. We like to imagine that doctors are familiar with the research literature, when in reality much of it is hidden from them by drug companies …We like to imagine that regulators only let effective drugs onto the market, when in reality they approve hopeless drugs, with data on side effects casually withheld from doctors and patients*" (Goldacre, 2014).

This is not the product of a conspiracy theorist, it is a factual account of industry practices by a respected researcher and medical journalist. Replace 'drugs' in this excerpt by RFR technologies and patients with users and it could have been written to describe the activities of the telecommunications industry. Regulators in this industry, such as the FCC, are as ineffective as the Food and Drug Administration (FDA) or their European counterparts in addressing governance and malfeasance in the pharmaceutical industry. Large corporations and telecommunication companies, from Apple to Samsung, Cisco to Vodafone, lobby governments for favourable 'safety' standards for their devices and equipment. They use their market power to keep the status quo. They bury safety notices in the small print or omit them altogether. They know the risks and they do not care about consumers. Recent 'phone-gate' scandals in France and the U.S. bear testament to an industry that cannot be trusted to self-regulate.[19]

There are other problems with extant studies in which the telecoms industry and ICNIRP claim to show little or no risk: *"Generally speaking, a poorly conducted study is more likely to result in a false negative (that is it fails to find a risk that is actually present) than in a false positive (mistakenly identifying and excess risk when none in fact exists). For the results of a negative study to be taken seriously, the study must be large and sensitive and gather accurate exposure data"* (Michaels, 2008, p. 84). It is clear from the research literature that poorly conducted, biased or manipulated studies are more likely to produce false negatives and show no effect,

[18] https://bioinitiative.org/research-summaries/

[19] https://www.chicagotribune.com/investigations/ct-cell-phone-radiation-testing-20190821-72qgu4nzlfda5kyuhteiieh4da-story.html

than robust rigorous studies which tend to show positive links between environmental toxins and health risks and demonstrate the existence of effects. Thus, Miller et al. (2018, p. 689) argue that epidemiological studies that result in false negatives may have significant flaws, indicating the need for additional *"epidemiological studies of brain cancer to be carried out [that] should include validated measures of exposure and/or biomarkers of possible impact of RFR on biological processes."* Nonetheless, a recent review of 24 epidemiological case-controlled studies illustrated an increased risk of gliomas and other brain tumours with long-term exposure to RFR from mobile phones (Bortkiewicz, Gadzicka, and Szymczak, 2017).

Michaels (2008, p. 81) illustrates that if epidemiological studies of general populations are not possible where carcinogens or toxins are concerned, then the approach scientists and regulators take is to study sub-populations in an industry: *"Much of what we know about the toxic effects of common environmental exposures, especially airborne exposures, comes from the study of workers."* A recent study by Peleg, Nativ, and Richter (2018) provides *"clear evidence"* of industrial exposure to RFR, within ICNIRP guidelines, and the incidence of hematolymphatic (HL) cancers in military and occupational settings. This study concludes that: *"The consistent association of RFR and highly elevated HL cancer risk in the four groups spread over three countries, operating different RFR equipment types and analyzed by different research protocols, suggests a cause-effect relationship between RFR and HL cancers in military/occupational settings"* (Peleg, Nativ, and Richter, 2018, p. 123). They add that: *"Overall, the epidemiological studies on excess risk for HL and other cancers together with brain tumors in cellphone users and experimental studies on RFR and carcinogenicity make a coherent case for a cause-effect relationship and classifying RFR exposure as a human carcinogen (IARC group 1)."*

The non-thermal effect 'denial problem' exists because of the multi-trillion dollar commercial and economic value of wireless technologies, and now 5G, coupled with the risk of litigation. From the 1990s, this led telecommunications and related industry associations to 'capture' regulatory agencies, such as the U.S. Federal Communications Commission (FCC) (Alster, 2015) to engage in disinformation and manipulate the press (Buchner and Rivasi, 2020; Hertsgaard and Dowie, 2018a; Walker, 2017; Fist, 1999: cf. Michaels, 2008; Oreskes and Conway, 2011;) and to participate in the 'institutional corruption' of scientists, their universities, and governments.[20] The net result of this standard business-operating procedure is that humans are unknowingly exposed to health risks. Governments appear to be willing partners in this and should be taking the side of citizens, not industry interests. While politicians and policymakers continue to behave like ostriches, the related health risks have risen significantly with the emergence of 5G.

4. CONCLUSIONS

Exposure of humans to non-ionizing radio frequency radiation (RFR) has increased dramatically over the past 20 years. Epidemiological and experimental research highlights the increased risk of pathophysiological conditions with current exposures to near field and far field sources of RFR. In light of the mounting scientific evidence, in May 2015, over 200 eminent scientists launched an international appeal to the United Nations and the WHO based on the conviction that there is a real and present danger to children, in particular, by what they consider outdated industry standards concerning microwave radio frequency radiation.[21] By April 2018, 244 scientists had signed the appeal: *"The scientific basis for their collective concern is "numerous recent scientific*

[20] https://today.law.harvard.edu/at-center-for-ethics-event-cell-phone-radiation-and-institutional-corruption-addressed-video/

[21] https://www.emfscientist.org/index.php/emf-scientist-appeal

publications have shown that EMF [i.e. electromagnetic fields, including RFR,] affects living organisms at levels well below most international and national guidelines. Effects include increased cancer risk, cellular stress, increase in harmful free radicals, genetic damages, structural and functional changes of the reproductive system, learning and memory deficits, neurological disorders, and negative impacts on general well-being in humans."

Industry-funded scientists and the majority of those in the ICNIRP are unconcerned and see little risk, apart from thermal effects, which they say the public are protected against by extant safety standards (Bandara and Carpenter, 2018; Belpomme et al. 2018; Buchner and Rivasi, 2020; Carlo and Schram, 2001; Cherry, 2002; Starkey, 2016;). Believe it or not, such differences of scientific opinion have bedeviled scientific progress across all disciplines. Hence, the tendency for scientists to be biased, to cling to dominant paradigms, and resist change in the face of scientific evidence is well acknowledged (Kuhn, 2012), and this is particularly true in relation to the wireless technology paradigm (Pockett, 2019; Fist, 1999). The following section will help the reader understand this contradiction better.

How can we make sense of the difference of opinion among scientists?

Sir Karl Popper was the foremost philosopher of science in the 20th Century. In 17th century Europe, people believed all swans were white. However, the discovery of black swans on the Swan River in Australia, led to the understanding that Swans could be both black or white. Thus, in *The Logic of Scientific Discovery* Popper (2005) argues that "*no matter how many instances of white swans we may have observed, this does not justify the conclusion that all swans are white."* Thus, a theory that all swans are white can be refuted by the sighting of just one black swan (Popper, 2014). Applying this logic to what is the dominant paradigm on the issue (but the minority view) of the safety of non-ionizing radio frequency radiation, just one study of the existence of non-thermal effects is sufficient to scientifically refute the theory that there are no non-thermal effects to non-ionizing radio frequency radiation. Fortunately, there are hundreds of such studies, with 68% of published research to 2017 finding non-thermal effects (Bandara and Carpenter, 2018).

There is a problem here, however. As indicated by the extensive bibliography published at the U.S. Naval Medical Research Institute by Dr. Zory Glaser and his team, the significant clinical and biological effects of RFR—both thermal and non-thermal—were identified and accepted by Soviet and Eastern-Bloc scientists. However, it is clear that U.S. scientists generally accepted that there were only thermal effects. In an extensive report in 1980, this is described as a philosophical difference based, perhaps, on cold-war politics (David, 1980). However, applying Popper's logic, Soviet, Czech and Polish researchers rightly posited the conjecture or theory that there was a range of biological effects, thermal and non-thermal—i.e. they posited the existence of white and black swans. Therefore, they instituted experiments to corroborate or refute their conjectures. However, as this review demonstrates, U.S. and Western scientists argued there were only white swans, ignored, dismissed, or buried all evidence of black swans, and acted to promote the interests of industry over that of public health.

Thus, we can see that what physicist and philosopher of science Thomas Kuhn referred to as a scientific revolution and paradigm change (Kuhn, 1962) may be underway in the scientific fields dealing with the risks to human health posed by RFR. However, vested interests—industry, political and scientific—in the dominant paradigm are resisting—the actions of the ICNIRP, FCC and FDA are testament to this. Unfortunately, UK citizens, especially children, will bear the health costs, now and into the future, of this latest paradigm war.

As with the tobacco industry before it (Michaels, 2008, 2009; McGarity and Wagner, 2008; Oreskes and Conway, 2011; Markowitz and Rosner, 2013), the telecommunications industry has been busy challenging all scientific findings that identify health risks with wireless technologies (Alster, 2015; Buchne and Rivasi, 2020). Not only does it have a convenient lacuna, when it comes to the body of research before and since 1976, it has also been conducting its own studies, some, but not all, of which deny the existence of non-thermal effects. With a record of conveniently burying its inconvenient truths, the telecoms industry has adopted the tobacco industry handbook when countering independent studies or explaining away research findings dating back to the 1930s viz. *"A demand for [more] scientific proof is always a formula for inaction and delay and usually the first reaction of the guilty … in fact scientific proof has never been, is not and should not be the basis for political and legal action."*[22] The same playbook was employed by the oil and coal industries when it came to global warming (Oreskes and Conway, 2011). The body of this report illustrated similar demands for more evidence and studies as the telecommunications industry and its funded scientists, particularly those in pseudo-independent bodies such as the ICNIRP, challenge the overwhelming body of independent research.

In a submission to the United Nations in 2015, over 250 scientists requested that it address *"the emerging public health crisis"* related to the use of RFR emitting devices.[23] They urged the United Nations Environmental Programme (UNEP) to review current exposure standards and to identify measures to substantially lower human exposures to microwave radiation. The scientists argued that existing *"guidelines do not cover long-term exposure and low-intensity effects"* and are *"insufficient to protect public health."* They note the urgency in this, as children are more vulnerable to the effects of RFR.

RFR is considered by the majority of independent scientists as an invisible source of potentially toxic pollution that scientific research across the sciences has identified as being harmful to biological systems and, ultimately, human health and well-being. Think of a smoke-filled bar of yore, where smokers and non-smokers alike are subjected to toxic carcinogens. Now, think of that same bar in countries where smoking is banned from such premises. However, have we replaced one hazard with another if one considers the RFR being emitted by the WiFi routers/access points, and radio units in all of the smart devices in pubs, cafes, restaurants, homes, schools, and the workplace. In the age of 5G and the Internet of Things (IoT), the scale of the dilemma that we have unthinkingly drifted into becomes clear. That is of course if one accepts the scientific evidence.

However, in 2020 the cumulative body and weight of scientific evidence should have governments and regulators take immediate action to change policy and implement appropriate safety standards for digital technologies such as 5G, as it is children that are most at risk. Concern has increased about such risks as the Advisory Group of 29 scientists from 18 countries recommended that non-ionizing RFR be prioritized by the WHO's International Agency for Research on Cancer (IARC) Monographs programme during 2020–24. They are concerned about the health risks identified by research over the past 9 years. So are the majority of independent researchers as they have called for non-ionizing microwave radiation to be reclassified as a Class 1 carcinogen, along with cigarette smoke (Miller et al., 2018). Furthermore, over 385 scientists and professionals in biophysics, medicine, health, and related fields have requested the United

[22] Attributed to S. J. Green BAT, https://www.who.int/tobacco/media/en/TobaccoExplained.pdf

[23] https://emfscientist.org/

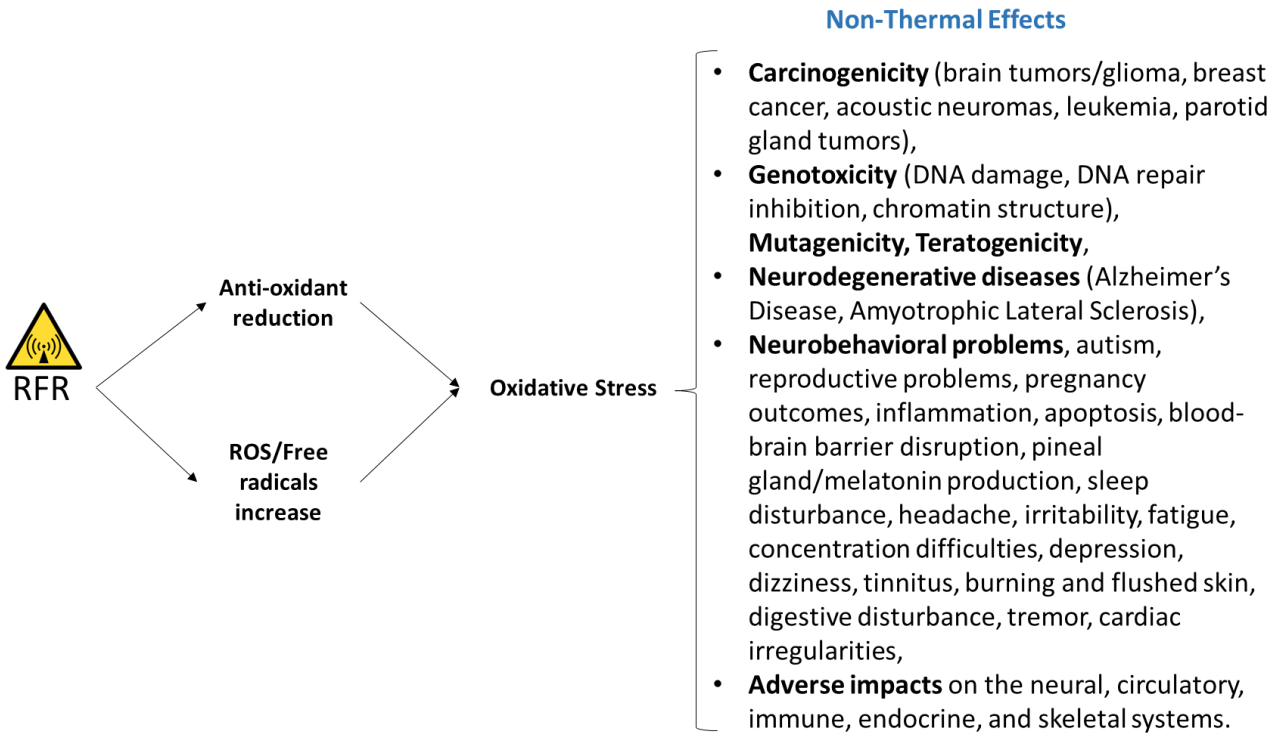

Figure 7 RFR Mechanisms and Outcomes

Nations to introduce a moratorium on 5G, given the related health risks for humans and threat to the environment.[24]

Dr. Christopher J. Portier, Associate Director, National Institute of Environmental Health Sciences and Director, Office of Risk Assessment Research, co-authored an article with Dr. Wendy Leonard in *Scientific American*, following the initial release of the NTP study findings in 2016. They conclude that *"Cellphones probably cause cancer if the exposure is close enough, long enough, and in sufficient magnitude. We don't yet know the risk for a given level of exposure in humans. We need more data in this area, not only for cellphones, but for bluetooth devices, WiFi and all the other RF-EMF devices out there. Until then, reduce your exposure whenever possible."* (Portier and Leonard, 2016). Arguments presented earlier, and also in the concluding sections of this paper, indicate that there is sufficient scientific evidence to halt any further deployment of wireless technologies such as 5G systems in the environment, due to the nature of the risks posed.

Figure 7 summarizes this report's findings and provides compelling reasons for why such action is necessary. It summarises the evidence of risk and indicates the role of specific mechanisms in producing the various impacts on human health and well-being. Each of the outcomes identified is independent of each other; hence, the risk of some form of ill-health to children and adults due to RFR exposure is highly probable as the source of the threat, RFR, is today ubiquitous. If we take cancers, the evidence presented above indicates that the incidence and the prevalence of frontal and temporal lobe brain tumours have increased with statistical significance; however,

[24] http://www.5gappeal.eu/signatories-to-scientists-5g-appeal/

a range of other cancers are now emerging as risk outcomes. Children are particularly vulnerable and their risk of exposure extremely high. However, due to the relatively low incidence of the cancers, their range, and the latency of cancers, the strength of epidemiological evidence demonstrating the carcinogenicity of tobacco smoke may not be possible. Nevertheless, what is of more immediate concern is the range of neurobehavioral and neurodegenerative diseases. In *Deceit and Denial*, Markowitz and Rosner (2013) conclude: *"the inability of epidemiology, toxicology, and statistics to demonstrate very small effects have been used by conservative critics who fashion the lack of statistical significance into the argument that such effects do not exist… In the absence of extraordinarily sophisticated and extremely expensive longitudinal studies, there is little chance that any but the most unambiguous and obvious problems will be uncovered…Environmental epidemiologists who work outside the laboratory attempt to study a complex world in which contamination and exposure to toxins can come from a variety of sources, including air, water, or land. Because of the many dynamic relationships between populations and their environments, it is virtually impossible to control the huge number of factors that can account for different lengths (and intensities) of exposure, specific chemicals or chemical mixes, or routes of exposure."* As indicated above the industry use this to sow doubt and conservative policymakers as an excuse for inaction. Nevertheless, the weight-of-evidence is there for all to see.

Thus, in light of the evidence, the *precautionary principle* should be applied and governments should implement policies that incorporate the risks as well as the benefits of wireless technologies such as 5G. Just to remind the reader what the *precautionary principle* means: *"When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically."*[25] We are well beyond that point, as this paper illustrates. The application of the *precautionary principle* is a statutory requirement in some areas of law in the European Union, as expressed in the *Charter of Fundamental Rights*. Thus, EU governments at least have a political and an ethical responsibility to act.

There is also a clear onus on scientists and practitioners in the computing and IT industry to act and ensure that the safety standards for all RFR and WiFi devices are reviewed in light of the recent scientific findings. To do otherwise would be irresponsible and unethical. There will be enormous resistance to change from vested interests and the political establishment. An excerpt from a recent article in *The Guardian* newspaper summarises the type of response to be expected from industry concerning research on RFR: *"Central to keeping the scientific argument going is making it appear that not all scientists agree. Towards that end, and again like the tobacco and fossil-fuel industries, the wireless industry has "war-gamed" science, as a Motorola internal memo in 1994 phrased it. War-gaming science involves playing offence as well as defence – funding studies friendly to the industry while attacking studies that raise questions; placing industry-friendly experts on advisory bodies such as the World Health Organisation and seeking to discredit scientists whose views differ from the industry's"* (Hertsgaard and Dowie, 2018a: cf. Michaels, 2008, 2009).

[25] https://en.wikipedia.org/wiki/Precautionary_principle

A personal opinion on the matters at hand

In 1985, when I was working on state-of-the-art satellite and terrestrial microwave communications systems, the only health and safety concern among the engineers was incidental or accidental exposure to RFR and related thermal effects. There was anecdotal evidence of non-thermal effects in military and occupational scenarios; however, these were rare and therefore not taken seriously. In 1995, however, while commissioning a satellite link for News International Corp. I measured the signal strengths of the mobile phones being used by engineers. These were a lot higher than I would have expected the safety guidelines to allow. From then on I never carried my mobile phone on or near my body. Colleagues continued to carry theirs on the belts.

In 2015, I made the transition from engineer to scientist having completed an MSc and PhD in information systems. At that point research focused on supporting risk and compliance in the financial industry using artificial intelligence technologies. I was also teaching the scientific method to PhD students, among other things. While discussing the risks that educational technology posed in the classroom with another risk professional, he made a strong statement regarding the risks that WiFi posed to children in the classroom and the home and that I should apply myself as a scientist to research. I was taken aback and highly skeptical of his statement. But given the seniority of his position in the financial industry I took him at his word. For the next four years, I studied the scientific literature applying Sir Karl Popper's *critical rationalism* to published peer-reviewed research to understand the risks to human health and well-being from non-thermal effects. I was only too conscious of the role of cognitive bias: in my case, I implicitly trusted the standards set by the IEEE, ICNIRP, and the FCC. However, in my first pass through the literature, I noted that there was something seriously amiss. From the perspective of the scientific method, the weight of the evidence was indicating that non-thermal effects did exist and children were especially at risk.

The U.S. National Institute of Science and Technology views risk as a function of four factors: *threat, vulnerability, likelihood,* and *impact*. In the digital age, the major RFR *threats* originate from far-field mobile and broadband antennae and near-field wireless devices such as Wifi access points and routers, mobile phones, smartphones, and all Wifi and Bluetooth devices. *Vulnerabilities* are manifested in human biological susceptibility to pulsed RFR signals acting at a cellular level, particularly in the central nervous system. These non-thermal biological effects are complex and differ from person to person, due to individual genetic disposition and general health and well-being: Socioeconomic status also plays a role. The overwhelming body of evidence indicates that human and animal cells are extremely sensitive to EMFs, particularly the pulsed signals from man-made RFR wireless technologies. This leads to an increase in reactive oxygen species (ROS), a reduction in anti-oxidants, and the development of oxidative stress. It is the individual biological response that determines whether oxidative stress is controlled and maintained within the 'normal' range and the risk of biological effects mitigated by the body's self-defense systems. Factors like age, health, lifestyle, and other issues like genetic predisposition will play significant roles in responding to oxidative stress and related outcomes.

The *likelihood* of a specific physical or biological effect materializing is a function of the frequency of exposure to a threat and the duration of such exposures. These may lead to chronic and persistent oxidative stress, which is linked with serious and equally chronic biological effects. Thus, the ubiquity of RFR threats in the environment and constant nature of exposures significantly increases the likelihood that the biological effects listed in Table 7 will materialize. The *impact* can be major at an individual level with chronic disease and in a very small proportion of people an early death from a range of cancers.

Extant research on man-made toxins and carcinogens indicate that when exposures are of high frequency and duration, then epidemiological studies will clearly identify exposure-outcome relationships if the threat is strong (e.g. cigarette smoke, asbestos, benzene), but where threats are less strong, epidemiological evidence may be more difficult to come by. Nevertheless, this report indicates that the weight of the evidence from human and animal studies demonstrates that the risks from RFR exposure are significant and that a range of non-thermal effects on human health and well-being is evident. That all this has been known since the early 1970s is unconscionable and unforgivable in terms of the response of policymakers and public health officials.

There are several measures that policymakers in the UK and elsewhere need to consider as a matter of urgency. That they have not already done so is, in my opinion, a serious dereliction of duty. Nevertheless, practical measures can be put into effect to help minimize risks to public health. This involves the urgent commission of epidemiological studies. As scientists have identified the risks and the key factors in creating intracellular oxidative stress that contributes to system-wide biological effects, research is required to determine how different levels of RFR exposures are related to the incidence and prevalence of oxidative stress within the population. Extant research has indicated what the tolerable levels of RFR may be for children, sensitive adults, and the general population. These levels are upwards of millions of times lower than those permitted by existing thermal guidelines. What is meant by tolerable levels is the degree of exposures, in terms of RFR field intensity, frequency of exposure, and duration of exposure, which different members of the population can tolerate while maintaining a natural balance in intracellular function, especially concerning recovery from the oxidative stress generated by exposure from RFR and normal human activities. It must be borne in mind that oxidative stress is associates with many chronic conditions. Hence, RFR-related non-thermal physical and biological-specific effects aside, it is logical to conclude that the presence of RFR will confer additional threats to those with pre-existing sensitivities, vulnerabilities, and chronic health conditions. There is, therefore, in my opinion, a degree of urgency involved.

Given the time horizon over which epidemiological studies are conducted and the urgency for policymakers to intervene to mitigate the risks to the general population, I believe that immediate remedial measures and controls are required to address the risks to public health. People should be informed of the risks with prolonged RFR exposure and educated on the measures and controls required to minimize these exposures and, particularly, those of their children. The key measures required to reduce exposure in terms of field intensity, frequency, and duration are distance, reduction in field intensity from transmitting devices and antennae, operation of devices in airplane mode, and powering off appliances when not in use. It is outside the scope of this report for me to describe specific steps, but they involve the application of common sense, much like the measures being advised to address the current pandemic.

Pre-eminent Philosopher of Science and champion of the scientific method, Sir Karl Popper states in *The Open Society, "[i]f we wish freedom to be safeguarded, then we must demand that the policy of unlimited economic freedom be replaced by the planned economic intervention of the state. We must demand that unrestrained capitalism give way to economic interventionism."* I believe that the economic freedom and self-regulation accorded to telecommunications and technology firms should be balanced with the need to protect the interests, health, and well-being of the citizenry. This was recently underlined in another context by Professor Shoshana Zuboff, who critiques the activities of BigTech firms and the consequences for individuals and society (Zuboff, 2015). Likewise, Professor Sherry Turkle (2017), paints an equally grim picture of the impact of digital technology on our general well-being. However, neither were aware of nor address, the fundamental way in which the same technologies create fundamental risks for

human health and well-being. It is clear to me that equally unaware and misinformed are politicians and policymakers, whether in nation-states and wider communities such as the EU.

It must be remembered that the introduction of wireless digital technologies happened in a piecemeal fashion from the 1970s. There was no cost-benefit analysis, in terms of the obvious benefits of enhanced communication and information access and exchange, versus the unintended consequences of and risks to human health. Driven by *'technological fundamentalism,'* and the general belief that digital technology is neutral and therefore carries no unintended consequences or risks, politicians, policymakers, and society were misled by the telecommunications industry in the U.S., UK, and Europe into believing that wireless technologies are safe. What should have happened, post-1976, when the risks were indicated by the U.S. Naval Medical Research Institute and in several studies up to the 1990s, is that governments should have followed Popper's general advice viz. limited the scope of technological change in line with independent scientific research on thermal and non-thermal risks, which predicted the outcomes for individuals and society. However, as Professor Nassim Taleb correctly argues *"[o]ur record of understanding risks in complex systems (biology, economics, climate) has been pitiful, marred with retrospective distortions (we only understand the risks after the damage takes place, yet we keep making the mistake), and there is nothing to convince me that we have gotten better at risk management"* (Taleb, 2012). The truth of the risks posed by RFR—4G, 5G and WiFi—is there for all to see. But it's not easy to access or understand the science and its findings, as I found over the past four years.

Popper (2014) indicates in his masterwork, *Conjectures and Refutations*, that scientific truth is difficult to achieve. That is certainly the case with RFR and non-thermal effects, for reasons outlined above. He also holds that people tend to be essentially *"good, but stupid"* and easily *"led by the nose"* by bad people: in the current context, these include self-serving, unethical industry figures, bad scientists, and those with conflicts of interest in the third and fourth estates. His theory explains how the press, the public, politicians, and policymakers, can be easily duped by industry, the ICNIRP, and a minority of scientists, among others. Considering, the lessons learned from what is, perhaps, the greatest environmental disaster of recent times involving the accident at the Chernobyl nuclear power plant, the award-winning HBO docudrama attributes the following quote to the scientist responsible for averting a global catastrophe, Dr. Valery Legasov:

> *"To be a scientist is to be naive. We are so focused on our search for truth we fail to consider how few actually want us to find it. But it is always there whether we see it or not, whether we choose to or not. The truth doesn't care about our needs or wants—it doesn't care about our governments, our ideologies, our religions—it will lie in wait for all time…Where I once would fear the cost of truth, now I only ask what is the cost of lies."*

We may never know the truth of how or why the telecommunications and technology industries, their business leaders, engineers, and scientists, acted as they did: Nor may we know what they knew of the risks and when they knew it or the lies they told. We may never know how unethical businessmen and bad scientists influenced policymakers: Nor may we know why politicians decided to side with industry and not public health interests or why they gave wireless technologies an unquestioning benefit of the doubt. The consequences of not facing the truth and addressing the risks RFR poses—as Markowitz and Rosner (2013) so eloquently state in the concluding paragraph of their excellent monograph, *Deceit and denial: The deadly politics of industrial pollution*—are that it may never *"be possible to evaluate the lost potential of individuals whose intelligence has been slightly lowered, whose behavior has become a bit more erratic, whose personalities have been altered in ways imperceptible to scientific measurement. We will never know the social, economic, and personal costs to society from the lost potential of our*

citizens." The only note of hope I can offer is that the widespread use of wireless technologies is relatively recent. Thus, if we act now to inform society of the known risks our wireless technologies pose, citizens can then be enabled to learn how to use their digital technologies to enrich their lives and livelihoods without endangering their health and well-being and that of their children. But first, we need to combat the deceit and denial of vested interests. We need to ensure that politicians and policymakers inform themselves of the full facts, not only the industry perspective, and to ensure that they act ethically and in the interest of public health and well-being.

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APPENDIX A: CANCER EVIDENCE BY CATEGORY

Brain tumors

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Tumors of the Meninges (Meningioma)

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Parotid Gland Cancer

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Ocular Cancer

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Cancers of the Breast (male and female)

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Leukemia

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Thyroid Cancer (male and female)

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Colorectal Cancers

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APPENDIX B: ICNIRP FINANCIAL REPORTS 2017-2018

From ICNIRP Annual Report 2018

Financial Report 2017*		
Income		
Subsidies		139.969,00
Workshops and Books		586,00
Total Income		**140.555,00**
Expense		
Staff & Training	- 84.461,00	
Meetings & Workshops	- 44.832,00	
Publications & Communication	- 8.013,00	
Insurance & Administrative Expense	- 3.218,00	
Total Expense	**- 140.524,00**	
Finance Income		0,00
Finance Costs	- 154,00	
Financial results	**- 154,00**	
Result of the Year	**123,00**	

Financial Report 2018*		
Income		
Subsidies		132.150,66
Workshops and Books		1.103,54
Total Income		**133.254,20**
Expense		
Staff & Training	- 86.283,39	
Meetings & Workshops	- 57.035,34	
Publications & Communication	- 5.577,23	
Insurance & Administrative Expense	- 2.063,71	
Total Expense	**- 150.959,67**	
Finance Income		0,00
Finance Costs	- 344,21	
Financial results	**- 344,21**	
Result of the Year	**- 18.049,38**	

APPENDIX C: PROFESSOR PALL'S ICNIRP CRITIQUE EVIDENCE

Reviews showing important health-related non-thermal effects of microwave frequency electromagnetic fields (EMFs). Specific effects and reviews, each reporting the effect in multiple primary literature studies.

1. **Effects on cellular DNA including single-strand and double-strand breaks in cellular DNA and on oxidized bases in cellular DNA; also evidence for chromosomal mutations produced by double strand DNA breaks.**

1. Glaser ZR, PhD. 1971 Naval Medical Research Institute Research Report, June 1971. Bibliography of Reported Biological Phenomena ("Effects") and Clinical Manifestations Attributed to Microwave and Radio-Frequency Radiation. Report No. 2.
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10. Makker K, Varghese A, Desai NR, Mouradi R, Agarwal A. 2009 Cell phones: modern man's nemesis? Reprod Biomed Online 18:148-157.
11. Yakymenko I, Sidorik E. 2010 Risks of carcinogenesis from electromagnetic Radiation and mobile telephony devices. Exp Oncol 32:729-736.
12. Yakimenko IL, Sidorik EP, Tsybulin AS. 2011 [Metabolic changes in cells under electromagnetic Radiation of mobile communication systems]. Ukr Biokhim Zh (1999). 2011 Mar-Apr;83(2):20-28..
13. Gye MC, Park CJ. 2012 Effect of electromagnetic field exposure on the reproductive system. Clin Exp Reprod Med 39:1-9. doi.org/10.5653/cerm.2012.39.1.1
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frequency electromagnetic field action. Rev. Environ. Health 3, 99-116. doi: 10.1515/reveh-2015-0001.
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18. Houston BJ, Nixon B, King BV, De Iuliis GN, Aitken RJ. 2016 The effects of radiofrequency electromagnetic Radiation on sperm function. Reproduction 152:R263-R276.
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20. Asghari A, Khaki AA, Rajabzadeh A, Khaki A. 2016 A review on Electromagnetic fields (EMFs) and the reproductive system. Electron Physician. 2016 Jul 25;8(7):2655-2662. doi: 10.19082/2655.
21. Pall ML. 2018 How cancer can be caused by microwave frequency electromagnetic field (EMF) exposures: EMF activation of voltage-gated calcium channels (VGCCs) can cause cancer including tumor promotion, tissue invasion and metastasis via 15 mechanisms. Chapter 7 in Mobile Communications and Public Health, Marko Markov, Ed., CRC press, pp 163-184.
22. Pall ML. 2018 Wi-Fi is an important threat to human health. Environ Res 164:404-416.
23. Wilke I. 2018 Biological and pathological effects of 2.45 GHz on cells, fertility, brain and behavior. Umwelt Medizin Gesselsha; 2018 Feb 31 (1).

2. **Lowered fertility, including tissue remodeling changes in the testis, lowered sperm count and sperm quality, lowered female fertility including ovarian remodeling, oocyte (follicle) loss, lowered estrogen, progesterone and testosterone levels (that is sex hormone levels), increased spontaneous abortion incidence, lowered libido**.

1. Glaser ZR, PhD. 1971 Naval Medical Research Institute Research Report, June 1971. Bibliography of Reported Biological Phenomena ("Effects") and Clinical Manifestations Attributed to Microwave and Radio-Frequency Radiation. Report No. 2 Revised.
2. Tolgskaya MS, Gordon ZV. 1973. Pathological Effects of Radio Waves, Translated from Russian by B Haigh. Consultants Bureau, New York/London, 146 pages.
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6. Makker K, Varghese A, Desai NR, Mouradi R, Agarwal A. 2009 Cell phones: modern man's nemesis? Reprod Biomed Online 18:148-157.
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16. Hensinger P, Wilke E. 2016. Mobilfunk-Studienergebnisse bestätigen Risiken Studienrecherche 2016-4 veröffentlicht. Umwelt Medizin Gesellsha; 29:3/2016.
17. Houston BJ, Nixon B, King BV, De Iuliis GN, Aitken RJ. 2016 The effects of radiofrequency electromagnetic Radiation on sperm function. Reproduction 152:R263-R276
18. Pall ML. 2018 Wi-Fi is an important threat to human health. Environ Res 164:404-416.
19. Wilke I. 2018 Biological and pathological effects of 2.45 GHz on cells, fertility, brain and behavior. Umwelt Medizin Gesselsha; 2018 Feb 31 (1).

3. Neurological and neuropsychiatric effects

1. Marha K. 1966 Biological Effects of High-Frequency Electromagnetic Fields (Translation). ATD Report 66-92. July 13, 1966 (ATD Work Assignment No. 78, Task 11). http://www.dtic.mil/docs/
citations/AD0642029 (accessed March 12, 2018).
2. Glaser ZR, PhD. 1971 Naval Medical Research Institute Research Report, June 1971. Bibliography of Reported Biological Phenomena ("Effects") and Clinical Manifestations Attributed
to Microwave and Radio-Frequency Radiation. Report No. 2 Revised.
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19. Hensinger P, Wilke E. 2016. Mobilfunk-Studienergebnisse bestätigen Risiken Studienrecherche 2016-4 veröffentlicht. Umwelt Medizin Gesellsha; 29:3/2016.
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4. **Apoptosis/cell death. Apoptosis is an important process in the production of neurodegenerative diseases that is also important in producing infertility responses.**

1. Glaser ZR, PhD. 1971 Naval Medical Research Institute Research Report, June 1971. Bibliography of Reported Biological Phenomena ("Effects") and Clinical Manifestations Attributed to Microwave and Radio-Frequency Radiation. Report No. 2 Revised
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INTERFACE

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Report

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Author for correspondence:
Martin Vacha
e-mail: vacha@sci.muni.cz

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Weak radiofrequency fields affect the insect circadian clock

Premysl Bartos[1], Radek Netusil[1], Pavel Slaby[1], David Dolezel[2,3], Thorsten Ritz[4] and Martin Vacha[1]

[1]Department of Experimental Biology, Section of Animal Physiology and Immunology, Faculty of Science, Masaryk University, Czech Republic
[2]Biology Centre of the Czech Academy of Sciences, Institute of Entomology, and [3]Department of Molecular Biology and Genetics, Faculty of Science, Branisovska 31, Ceske Budejovice, Czech Republic
[4]Department of Physics and Astronomy, University of California Irvine, Irvine, CA, USA

DD, 0000-0001-9176-8880; TR, 0000-0002-2713-539X; MV, 0000-0002-4856-6826

It is known that the circadian clock in *Drosophila* can be sensitive to static magnetic fields (MFs). Man-made radiofrequency (RF) electromagnetic fields have been shown to have effects on animal orientation responses at remarkably weak intensities in the nanotesla range. Here, we tested if weak broadband RF fields also affect the circadian rhythm of the German cockroach (*Blatella germanica*). We observed that static MFs slow down the cockroach clock rhythm under dim UV light, consistent with results on the *Drosophila* circadian clock. Remarkably, 300 times weaker RF fields likewise slowed down the cockroach clock in a near-zero static magnetic field. This demonstrates that the internal clock of organisms can be sensitive to weak RF fields, consequently opening the possibility of an influence of man-made RF fields on many clock-dependent events in living systems.

1. Introduction

Radiofrequency (RF) fields accompanying modern man are suspected to interfere with biological processes and have been extensively examined (reviewed e.g. in [1,2]). The impact of electromagnetic noise on animal magnetoreception is well documented and the compass sense of birds [3–7], mice [8] and arthropods [9,10] was lost or biased [11] if animals were exposed to RF. RF fields have been suggested to interfere specifically with radical-pair (RP) magnetoreception mechanism [3,12–14], and it has been suggested that key steps in magnetic field (MF) reception may be mediated by Cryptochrome protein (Cry) ([12], reviewed in [15]). Gene silencing identified *Blatella germanica* Cry as essential for detection of directional changes in MFs [16]. Cry is known to be a component of the biological clock system. Two independent studies have shown that static MFs with intensities comparable to the Earth's MF changed the circadian rhythm in *Drosophila* [17,18]. The MF effect was dependent on functional *cry* gene and the wavelength of light. Aside from magnetoreception and the circadian clock, Cry is involved in several cellular and organismal functions [19,20] and pathologies [21,22]. The possibility that MF and especially widespread weak RFs interfere with Cry cellular tasks in general is both intriguing and pungent. Here, we set out to investigate if the circadian rhythm of *Blatella* is affected by MFs and weak broadband RF fields.

2. Results and discussion

To explore a role of magnetic and RF fields on the circadian clock, we investigated the free-running rhythm of locomotor activity of the German cockroach (*Blatella germanica*) in darkness and two intensities of UV 365 nm light combined with three intensities of static MF and three intensities of RF fields.

First, two intensities of UV 365 nm constant light which reliably lengthen but still not abolish the free-running period were set: dimmer: 1.7×10^{-6} Wcm^{-2} and

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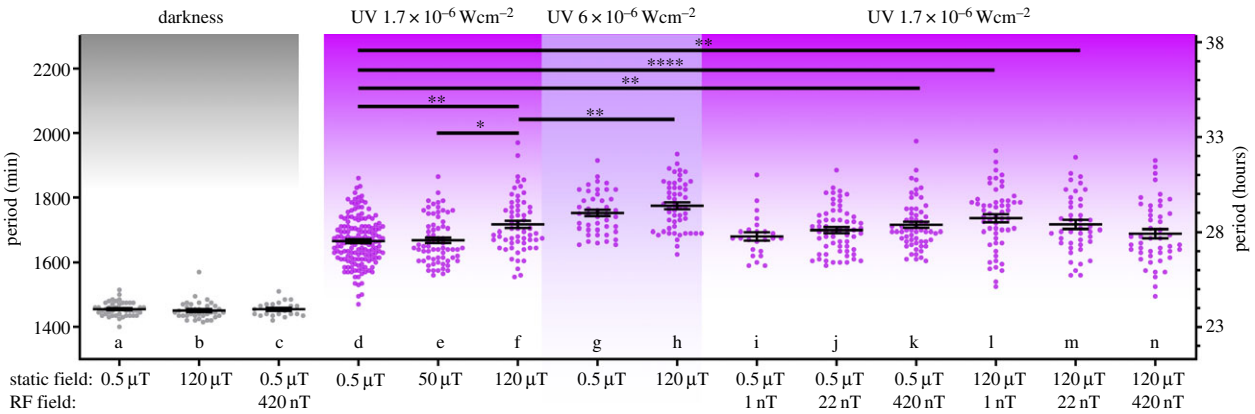

Figure 1. Periods of locomotor activity under permanent darkness or UV light 365 nm. The light lengthens the period proportionally to its intensity as well as static 120 µT and 420 nT RF field separately do. Light is necessary for both MF and RF fields effects. The threshold is between 50 and 120 µT for MF and between 22 and 420 nT for RF. Mean with s.e.m. are figured, Tukey's multiple comparisons test used, $*p < 0.05$, $**p < 0.01$, $***p < 0.001$, for all significant differences, $****p < 0.0001$, see electronic supplementary material, figure S1. (Online version in colour.)

brighter: 6×10^{-6} Wcm^{-2}. When keeping the MF at both 0.5 µT and 120 µT, the observed lengthening of the free-running period in *Blatella* reflects the intensity of light (electronic supplementary material, figure S1 and figure 1f,h) and is consistent with *D. melanogaster* results [17].

As a second step, the role of a static MF was tested. In the dimmer UV light 1.7×10^{-6} Wcm^{-2}, we used three intensities: near-zero 0.5 µT (figure 1d), Earth-like 50 µT (figure 1e) and hypermagnetic 120 µT (figure 1f). While significant lengthening of the period was evident when the MF was strengthened from 50 µT to 120 µT, no change of the period occurred between 0.5 and 50 µT (figure 1). Under brighter light 6×10^{-6} Wcm^{-2}, lengthening of the period between 0.5 µT (figure 1g) and 120 µT (figure 1h) was not significant, likely to be due to getting close to saturation limit. The system clearly needs the light to become magnetosensitive as no change of the rhythm was detected in darkness. The static MF effects observed in our study are clearly dependent on the presence, intensity and wavelength of light—all in line with two *Drosophila* reports from Yoshii *et al.* [17] and Fedele *et al.* [18].

In our system, the application of a 120 µT MF slowed down the circadian rhythm compared to both 0.5 and 50 µT fields and resembles the impact of UV light (figure 1). However, the same-treatment under 505 nm green light 4.5×10^{-6} Wcm^{-2} shortened the period of the rhythm (electronic supplementary material, figure S2). Antagonistic effects of UV-blue versus blue-green parts of the spectra have been reported several times in animal magnetoreception (rev. e.g. in [23]) and provide the most likely explanation for ambiguous or opposite responses of *Drosophila* clock system to MFs [17,18]. The nature of this antagonism is beyond the scope of our work, but is clearly in line with involvement of light-dependent magnetoreception in animal clock systems.

Having established that static MF effects occur on the cockroach circadian clock, we turn to studying the effects of weak RF MFs. In this study, we choose to apply RF broadband noise of different intensities, because it has been argued that such fields may be a promising diagnostic test for the presence of an underlying RP mechanism [13].

Application of RF broadband noise in near-zero MF and dim 1.7×10^{-6} Wcm^{-2} UV light did not have a significant effect for a 1 nT (figure 1i) or 22 nT RF field (figure 1j), but reached significant level of slowing the rhythm for a 420 nT RF field (figure 1k), when compared with the near-zero MF dim UV light condition without an RF field (figure 1d). Therefore, the effect of the 400 nT RF field (figure 1k) was statistically indistinguishable from the effect of the 120 µT static MF (figure 1f). In contrast to the effects under dim UV light, no effect of a 420 nT broadband RF field could be observed in darkness (figure 1c), just as no effects of a 120 µT could be observed in darkness (figure 1b). This suggests a similar mechanism of action of the RF broadband field to the static MF. However, it is noteworthy that the intensity of the RF field required to slow down the circadian clock was much lower than that required for a static MF to do the same. The threshold for static MF field effects to occur lies between 50 and 120 µT, indicating that the clock system is between 100 and 300 times more sensitive to RF field than to static MF.

When RF broadband noise combined with 120 µT MF and dim 1.7×10^{-6} Wcm^{-2} UV light were applied, no significant effects on the circadian clock were seen for 1 nT (figure 1l) and 22 nT (figure 1m) RF fields again. Nevertheless, a subtractive relationship may be hypothesized for RFs and MF if applied simultaneously since a combination of maximal RF 420 nT and maximal MF 120 µT (figure 1n) did not differ from control near-zero condition (figure 1d). Such interference between MFs and RFs has its parallel in experiments on animal orientation discussed above but its physical nature, likely to be dependent on the (an)isotropy of hyperfine interactions within RP (P Hore 2018, personal communication), is beyond the scope of the work. The observed threshold of broadband RF field effects between 22 and 420 nT should be considered dependent on background MF and light intensities, hence potentially, even more sensitive. Should the sensitivity of the clock system be as high as to about tens of nT of cumulative intensity, biological experiments in standard laboratories or incubators may face biasing problems, because background RF intensity may often reach this level (electronic supplementary material, figure S3; 30 nT for bench measurement outside the shielded chamber).

3. Conclusion

Our data show that the circadian rhythm of the insect species *B. germanica* is sensitive to both static MF and RF fields in a

light-dependent manner. While a number of studies have shown physiological effects of weak RF fields as mentioned in the Introduction, all of these effects were observed on magnetic orientation responses of the respective animals and one might therefore argue that the effects of RF fields may be limited to highly specialized responses of navigating animals. Having no ambitions to explain the nature of observed phenomena, our study provides evidence that weak broadband RF noise impacts the insect clock system which turned out to be even more sensitive to RF than to static MFs. Studies of free-running period are always performed under artificial conditions devoid of any natural synchronizing inputs (Zeitgebers) which limits all conclusions referring to normal conditions on the Earth. Nevertheless, since the number of circadian clock-dependent health problems grows in population and since urban areas are polluted by RF noise even more than it was used in this study (e.g. [6]), the evidence of interference between RF and clock controlling systems is worth of concern and deep investigation.

4. Material and methods

4.1. Testing scheme

Adult German cockroaches immobilized by CO_2 were individually and regardless of sex transferred into glass Petri dishes on a layer of transparent agarose gel. Forty dishes were placed on a glass pane on a wooden table into an electromagnetically shielded chamber illuminated from above and monitored by a camera from below. Silhouettes of cockroaches were captured every 5 min for 14 days and free-running movement rhythms were investigated. Thermal (23.8°C ± 0.6°C), light and magnetic conditions were held constant for the entire testing period and were checked prior to and after the experiment. Different experimental conditions alternated (see table of primary data available online). Experimenter and data evaluator were always blind as to what type of RF field and MF were set.

4.2. Light conditions

Two intensities of UV light (365 nm) and three intensities of green light (505 nm) and darkness were generated by LED lamps. Petri dishes had opaque white walls and a light-dispersing sheet of filter paper covered them.

4.3. Magnetic conditions

Three static MFs intensities were set: total vector 0.5 µT ± 0.4 µT (residual field, no current sent to coils), total vectors 50 µT and 120 µT (space deviation ± 0.5 µT) and inclinations 45° (chosen for technical reasons) were generated by three-dimensional Merritt coils (2.5 × 2.5 × 2.5 m) located inside the chamber and fed by custom-made, computer-controlled power supplies.

4.4. RF conditions

Four experimental intensities of the broad band RFs noise (of 0, 1, 22 and 420 nT) were generated by a loop antenna constructed as a single horizontal winding of coaxial cable around the walls of the chamber in the plane of the testing table. The shield of the coaxial cable was removed opposite the feed.

4.5. Evaluation and statistics

For motor activity detection, 4032 samples were analysed and the number of body shifts greater than 1 cm was calculated automatically using Matlab based custom-made image analysis software RoachLab. Actograms and their statistical significances were analysed by the Lomb–Scargle method plugin ActoJ of ImageJ software (1.49v; NIH). All tested conditions were visualized and statistically evaluated by ANOVA and Tukey's multiple comparisons test (GraphPad Prism 7.04). Only clearly rhythmic animals with statistical significance PN > 20 were scored and analysed (percentage of rhythmic animals is given in electronic supplementary material, figures S1 and S2).

Data accessibility. Complete list of primary data is available online at: https://is.muni.cz/www/vacha/supplementary_materials_blatella_rhythms/Blatella_rhythms_primary_data.xls.

Competing interests. We declare we have no competing interests.

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Building science and radiofrequency radiation: What makes smart and healthy buildings

Frank M. Clegg[a,*], Margaret Sears[b], Margaret Friesen[c], Theodora Scarato[d], Rob Metzinger[e], Cindy Russell[f], Alex Stadtner[g], Anthony B. Miller[h]

[a] Canadians for Safe Technology; Business Advisory Board, Environmental Health Trust; Canadians for Safe Technology, PO Box 33, Maple Grove Village Postal Outlet, Oakville, ON L6J 7P5, Canada
[b] Ottawa Hospital Research Institute; Prevent Cancer Now; RR 1, 107 Mast Lane, Dunrobin, ON K0A 1T0, Canada
[c] Canadians for Safe Technology; Environmental Health Association of Manitoba, 43 Rutgers Bay, Winnipeg, MB R3T 3C9, Canada
[d] Environmental Health Trust, PO Box 58, Teton Village, WY, 83025, USA
[e] Safe Living Technologies Inc, 7 Clair Road West, PO Box 27051, Guelph, ON N1L 0A6, Canada
[f] Physicians for Safe Technology, PO Box 7443, Menlo Park, CA, 94026, USA
[g] President of Healthy Building Science Inc, 369-B 3rd Street #521, San Rafael, CA, 94901, USA
[h] Former Advisor to the World Health Organization; Dalla Lana School of Public Health, University of Toronto, 155 College St, Toronto, ON M5T 3M7, Canada

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ABSTRACT

Radiofrequency radiation (RFR), used for wireless communications and "smart" building technologies, including the "Internet of Things," is increasing rapidly. As both RFR exposures and scientific evidence of harmful effects increase apace, it is timely to heed calls to include low RFR levels as a performance indicator for the health, safety and well-being of occupants and the environment.

Adverse biochemical and biological effects at commonly experienced RFR levels indicate that exposure guidelines for the U.S., Canada and other countries are inadequate to protect public health and the environment.

Some industry liability insurance providers do not offer coverage against adverse health effects from radiation emitted by wireless technologies, and insurance authorities deem potential liability as "high." Internationally, governments have enacted laws, and medical and public health authorities have issued recommendations, to reduce and limit exposure to RFR.

There is an urgent need to implement strategies for no- or low-RFR emitting technologies, and shielding, in building design and retrofitting. These strategies include installing wired (not wireless) Internet networks, corded rather than cordless phones, and cable or wired connections in building systems (e.g., mechanical, lighting, security). Building science can profit from decades of work to institute performance parameters, operationalizing prudent guidelines and best practices. The goal is to achieve RFR exposures that are ALARA, "As Low As Reasonably Achievable."

We also challenge the business case of wireless systems, because wired or cabled connections are faster, more reliable and secure, emit substantially less RFR, and consume less energy in a sector with rapidly escalating greenhouse gas emissions.

1. Introduction

Radiofrequency radiation (RFR) exposures are increasing rapidly with wireless technologies, but rarely are the terms "building science" and "RFR" used in the same sentence. Building science attends to the physical performance of buildings, the comfort, health, safety of occupants, and the larger natural and built environment [1]. "Science" includes physics and the electromagnetic spectrum, including RFR.

Building science considers the building *as a system* and devises effective solutions for design concerns. The primary system elements include: the building enclosure (building envelope); inhabitants (humans, animals, and/or plants); building services (electrical/mechanical/

* Corresponding author. Canadians for Safe Technology, Business Advisory Board, Environmental Health Trust, Canadians for Safe Technology, PO Box 33, Maple Grove Village Postal Outlet, Oakville, ON L6J 7P5, Canada.

E-mail addresses: frank@c4st.org (F.M. Clegg), meg@preventcancernow.ca (M. Sears), ehamanitoba@gmail.com (M. Friesen), theodora.scarato@ehtrust.org (T. Scarato), rob@slt.co (R. Metzinger), cindyleerussell@gmail.com (C. Russell), alex@healthybuildingscience.com (A. Stadtner), ab.miller@sympatico.ca (A.B. Miller).

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electronic systems); site, with its landscape and services infrastructure; and external environment (landscape, weather and micro-climate) [1]. To achieve a well-performing building, all these elements must be harmonized.

Historically, awareness of indoor environmental quality heightened with novel materials following World War II, and was bolstered with improved air-tightness during the energy crisis of the 1980s. Minimizing chemical off-gassing of composite materials, maintenance products and mold is advised to optimize indoor air quality and occupants' health [2]. Similarly, magnetic and electrical fields and currents with early electrical applications are also associated with adverse health effects. Assiduous adherence to electrical codes and best practices, and isolation of potentially problematic equipment, are among measures to address ongoing power-frequency, "dirty power" and ground current concerns [3,4].

Today engineers, architects, planners and others are challenged to keep abreast of research and policies that address potential harm from wireless technology. This paper builds on long-standing recommendations to expand the typical scope of building science to consider RFR [3,4]. It briefly describes RFR in the electromagnetic spectrum, use of wireless technology in "smart" buildings, and summarizes peer-reviewed, scientific research regarding biological effects on human and environmental health. Key reasons as to why action should be taken include potential liability risks when technology is not implemented safely. International measures and guidelines for lower RFR exposure are highlighted. Finally, practices are outlined and recommendations made to minimize the impact of RFR on public and environmental health in the design, construction and maintenance of safer, modern buildings.

Internationally, a broad range of standards and policies limit magnetic and electric fields over a broad range of frequencies, including RFR [5]. It is beyond the scope of this paper to address the full electromagnetic spectrum.

2. Radiofrequency radiation explained

2.1. The electromagnetic spectrum

The electromagnetic spectrum (Fig. 1) is a continuum ranging from low to high frequencies, associated with the longest to shortest wavelengths, respectively [6,7]. A distinction is made between high frequency non-ionizing versus higher frequency ionizing radiation that has enough energy to displace electrons and "ionize" atoms and molecules. Ionizing radiation includes ultraviolet light, X-rays and gamma rays. Below these frequencies, non-ionizing radiation includes visible and infrared light, and frequencies for wireless communications and radar. Lower frequencies are used to broadcast commercial radio and television, while alternating currents at 50 or 60 cycles per second or Hertz (Hz) are in power lines and building wiring.

RFR is sent wirelessly from a transceiver (e.g., Wi-Fi router) to another transceiver (e.g., computer) and vice versa. The RFR frequency range covered in guidelines and standards is generally from 3 kHz to 300 GHz and includes the microwave (MW) range. The terms RFR and MW are sometimes used interchangeably. Uses of frequency ranges overlap, so there are no precise boundaries for any particular technology. Information is encoded in the modulation (superimposed higher frequency irregularities) on a radiofrequency carrier wave. While the frequency of the carrier wave is stated in the manufacturer's specifications for various devices, the actual human exposure includes these overlain or superimposed signals [6]. Modern devices utilize multiple carrier frequencies.

Devices that receive and emit RFR include personal items that communicate wirelessly such as: cordless and mobile phones; computers, laptops, tablets and peripheral equipment; monitors (e.g., for babies, or medical purposes); toys, video game and entertainment systems; virtual reality headsets; GPS systems; and Bluetooth-enabled "wearables" such as for personal fitness. RFR-emitting equipment that may be installed in buildings includes: wireless routers and associated mesh networks; "smart" utility metering; identification and security systems; cell boosters; power transfer/battery charging stations; and the "Internet of Things" (IoT) such as building systems (e.g., heating, ventilation and lighting), and appliance monitoring and control.[1] These devices are designed to use a number of presently used plus new radiofrequency bands, from 600 MHz to GHz frequencies. Fifth generation or 5G frequencies that are being licensed by the U.S. Federal Communications Commission (FCC) will include lower frequencies used for television, through higher frequencies into the millimeter wavelength range (above 30 GHz) [9]. Higher frequencies provide greater bandwidth, albeit with shorter range and poorer penetration of structures and vegetation; these are discussed in Section 3.1.

Microwave ovens and other RFR-emitting devices (e.g., Wi-Fi and cell phones) rely on similar frequencies, but the power and signal characteristics are different. Ovens heat with 1000 Watts (W) of continuous-wave radiation, whereas wireless devices are lower power; for example a cell phone is a two-way microwave radio, using on average less than 1 W of modulated radiation. Wireless communications signals, however, are in short bursts, that are biologically active, independent of the carrier frequency [10,11]. Another key feature of anthropogenic electromagnetic radiation is polarization; i.e., that the waves may be in one plane [12].

2.2. Regulatory history of RFR in the United States

In the U.S., the FCC authorizes and licenses devices, transmitters and facilities that generate RFR [13]. The U.S. does not have federally developed safety limits, as the Environmental Protection Agency never developed biologically based limits. The current FCC RFR exposure limits were adopted in 1996 based on recommendations from the National Council on Radiation Protection and Measurements (NCRP) [14], the American National Standards Institute (ANSI) and the Institute of Electrical and Electronics Engineers, Inc. (IEEE); specifically *IEEE C95.1–1991* and *ANSI/IEEE C95.1–1992*. None of these institutes have expertise in public health or biology. The FCC RFR exposure guidelines have not been substantially revised since 1996.

Presently, frequency bands between 9 kHz and 275 GHz have been allocated for various communications uses by the FCC [15].

2.3. RFR guidelines

The FCC RFR limits for public exposure reference three metrics: 1) the "Specific Absorption Rate" (SAR) is the rate at which RF energy is absorbed by human tissue; 2) power density, the rate of deposition of energy per unit area, is a function of the electrical and magnetic fields, at a particular frequency; and 3) the electrical field strength [7]. SAR limits apply to wireless wearable devices, cell phones and other items held close to the body. Power density limits apply to exposures at a distance, such as from cellular antennas and Wi-Fi.

2.3.1. Specific Absorption Rate (SAR)

The FCC and other governments' agencies require that all wireless devices such as cell phones or computers comply with SAR limits when the device is operating at its maximum power, before being placed on the market.

SAR is a measure of RFR energy dose to parts of the body closest to antennas, in the "near field," such as from the personal use of wireless devices. SAR is usually expressed in units of Watts per kilogram (W/kg) or milliwatts per gram (mW/g). The SAR for a given power density varies according to equipment details, the frequency and modulation,

[1] IoT is the comprehensive plan to connect billions of physical devices around the world to the Internet, collecting and sharing data.

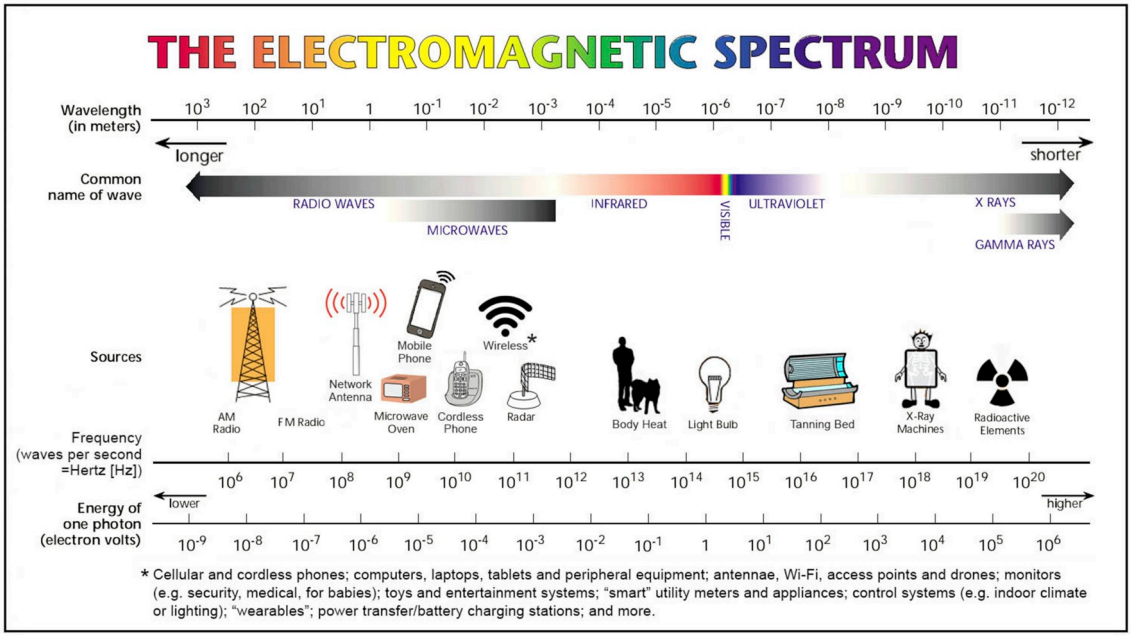

Fig. 1. The Electromagnetic spectrum (presented with permission) [8].

and the absorptive and reflective properties of the body or structure being exposed [7].

The FCC promulgated both public and occupational SAR limits. For the general public (commercial devices), the SAR limits for the head and the body are 1.6 W/kg averaged over a 1 g cube of tissue, and 4 W/kg averaged over a 10 g cube of tissue for ears, hands, feet, wrists and ankles [16]. Workers may be exposed to higher levels; occupational SAR limits are double those for the general public in the U.S., and five-fold greater for workers in "controlled environments" in Canada [17] as well as the many countries relying upon International Commission on Non-ionizing Radiation Protection (ICNIRP) guidelines [18].

Researchers have long criticized the SAR as an inadequate metric as it is measured in a mannequin – a liquid-filled phantom [19]. This does not capture the complex characteristics and interactions of living tissues' electromagnetic properties, or of RFR signals (e.g., the wave perturbations necessary to transmit information may cause additional biological impacts) [20]. FCC SAR limits and the measured SAR levels can be found in the manufacturer's instructions that come with every commercially sold wireless device, or on the manufacturer's website.

SAR testing protocols do not require cell phones and devices to be tested touching the body/skin or in novel configurations such as for virtual reality, despite the fact that this is the way they are often carried and used today [20,21,22]. Some cell phones are tested at as much as 25 mm separation distance. The national agency regulating radio-frequency radiation in France (ANFR) tested 450 cell phones in various configurations. The SAR exceeded the standard for 90% of the models that were tested as if they were contacting the body [23,24]. More than a dozen models were withdrawn from the market or had software updates to reduce RFR emissions.

2.3.2. Power density

Power density measurements address compliance in buildings or outdoor environments, such as when concerns are raised about RFR exposures from a nearby cell tower or from the Wireless Local Area Network (WLAN) system in a school. The FCC exposure limits range from 0.4 to 1.0 mW/cm^2 (4000 to 10,000 mW/m^2) [16] for commonly used frequencies.

Power density may be expressed as milliWatts or microWatts per square centimeter (mW/cm^2 or μW/cm^2), or milliWatts per square meter (mW/m^2).

For comparison, 1 mW/cm^2 = 1000 μW/cm^2 = 10,000 mW/m^2.

2.3.3. Electric field

"Electromagnetic" refers to both electrical and magnetic fields (EMF). Limits are established for electric fields, reported as volts per meter (V/m). Electric fields are commonly measured and reported during surveys of radiofrequency exposures, to characterize electromagnetic fields (EMF) across a broad range of frequencies [7].

2.3.4. Exposure attenuation

RFR reductions are generally reported as decibels. This is a non-linear, logarithmic scale, such that a signal that is 10 dB lower than another, is one tenth the signal strength of the comparator [25].

3. Information technologies and building science

Indoor environmental quality (IEQ) in more highly developed countries has advanced in terms of thermal comfort, air quality and construction for environmental performance (e.g., insulation), for example with guidance and classifications by The World Green Building Council [26] or Leadership in Energy and Environmental Design (LEED) [27]. These factors translate into familiar physical sensations of warmth, fresh air and comfort, versus cold drafts and stuffy air. Over the past decades, understanding of the modern sources of lower frequencies and now RFR within and surrounding building assemblies, and effects on inhabitants and surroundings, has gained recognition [3,28].

3.1. Developing technologies

Beyond Wi-Fi, a recent trend is the integration of wireless controls for lighting and heating/ventilation, as well as wireless security and audio/visual technology systems in buildings. "Smart buildings," with "smart systems" and "smart appliances" allow users to monitor and to control many interconnected mechanical and electronic systems via computers or "smart phones." Utility providers are utilizing "smart meters" for electricity, gas and water to transmit usage data electronically using RFR. Wireless charging stations for many items, from electronic devices to vehicles, may be additional sources of EMF.

Plans for the burgeoning IoT and 5th Generation (5G) wireless services are to transport large volumes of data quickly (e.g., for videos).

The proposed evolution of the “smart city” will imbue entire buildings and neighborhoods with higher levels of currently used frequencies, as well as the higher frequencies into millimeter wavelengths, which carriers plan to use in 5G [29]. A European Parliament report "5G Deployment: State of Play in Europe, USA, and Asia" explains how 5G radio emissions are different from those of previous generations because of their complex, highly focused, beam-formed transmissions, and that “it is not possible to accurately simulate or measure 5G emissions in the real world” [30].

Environments with very low RFR exposures can be achieved by choosing wired and fiber-optic cable connections, to buildings and throughout buildings. In fact, RFR is not only unnecessary for a “smart building;” wireless options will not match the bandwidth or reliability of fiber-optic or other cable options (“wired”) [31]. Wired options are faster and more secure, and require much less energy to operate [29,32], making them safer for human and environmental health.

4. Adverse health effects of RFR

4.1. Introduction

In many countries, guidelines and standards to protect the public from adverse effects of radiofrequency radiation (RFR) are based on an assumption that harm results only from excessive heating of tissue (thermal effects); however, numerous scientific publications document that RFR affects living organisms at exposures within regulatory parameters, at “non-thermal” levels.

“Microwave assisted chemistry” accelerates particular chemical reactions with low levels of RFR [33,34], and has been commercialized [33,35]. In living systems, the acceleration of some chemical reactions would cause molecular damage, chemical imbalances and dysfunction, and is consistent with observations of significant effects in humans, animals, plants and isolated cells.

Effects observed in studies of humans exposed to non-thermal levels of RFR include: cancer; early childhood developmental problems; brain, sperm and DNA damage; as well as electromagnetic hypersensitivity.

4.2. Cancer

4.2.1. RFR classified as a possible human carcinogen

The adequacy of RFR regulatory limits was challenged in 2011 when an expert panel convened by the International Agency for Research on Cancer (IARC) of the World Health Organization classified RFR (100 MHz–300 GHz) as a Group 2B, *possible* human carcinogen, largely based on the human epidemiological evidence of increased risk of glioma [36,37], a type of brain cancer. This classification includes wireless frequencies from all types of RFR-emitting devices, including Wi-Fi. In 2019, an IARC advisory group recommended reassessment of the 2011 classification, in light of recent animal research [38].

4.2.2. Subsequent evidence supports upgrading the IARC classification

In 2018, Miller et al. concluded that as a result of human epidemiology, and animal studies published following the IARC 2011 panel meeting, RFR should be categorized as a Group 1 *known* human carcinogen [39]. Hardell and Carlberg came to the same conclusion [40]. Tobacco smoke and asbestos are in Group 1.

The main human evidence for this proposed classification upgrade is a large French epidemiological study [41], as well as a meta-analysis of pooled case-controlled studies in Sweden [42]. In addition, a 2018 Israeli occupational exposure study concluded that overall the evidence “make[s] a coherent case for a cause-effect relationship and classifying RFR exposure as a human carcinogen (IARC group 1)” [43]. A case series also reports breast cancers associated with carrying a cell phone in the bra [44].

Canadian data (2001–2004) showed evidence of doubled risk of developing glioma for adults who used cell phones for 558 lifetime hours or more [45]. Consistent with the increasing use of cell phones, there was a statistically significant increase in incidence of primary malignant brain and central nervous system tumors in children and adolescents in the U.S. between 2000 and 2010 [46], and brain tumors subsequently became the most common malignancy in children and adolescents, with disease shifting to more aggressive gliomas [47].

Further supporting evidence came from three recent RFR rodent studies. The first two studies reported higher incidence of cancers in male rats exposed to RFR: 1) a $30 million study by the U.S. National Toxicology Program (NTP) of the National Institutes of Environmental Health Sciences (NIEHS), studied radiation simulating RFR intensity from cell phones [48]; and 2) a study by the Italian Ramazzini Institute [49] that was conducted at lower intensities (below FCC limits) designed to mimic radiation from cell towers. The tumors found in these large-scale studies were of the same histotype as in some human epidemiological cell phone studies.

A third large study demonstrated increased initiation and acceleration of tumor growth with RFR when the exposure was in conjunction with a cancer-causing chemical [50], replicating findings of a 2010 study [51].

4.3. Early life stages

During their rapid development, the embryo, fetus, infant and child are more vulnerable to many environmental insults, and impacts are potentially lifelong. Various life stages have different vulnerabilities

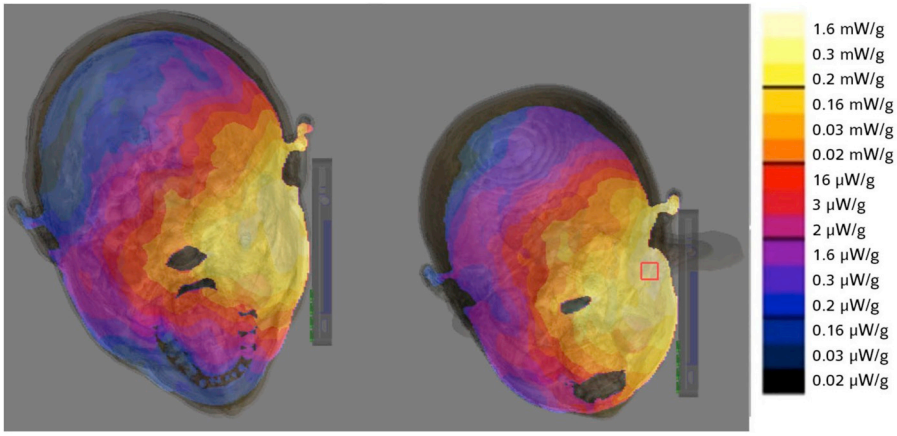

Fig. 2. Specific Absorption Rate (SAR) in adult and child (age 6 years) male heads with phone in talk position. The scale is 50 dB with 0 dB = 1.6 mW/kg. From work of Claudio Férnandez, 2018 [20] (used with permission of Environmental Health Trust).

and susceptibilities to RFR [52,53,54,55]. Modeling indicates that children absorb substantially higher RFR doses from cell phones, in deeper brain structures, than do adults (Fig. 2) [20]. Research has also found proportionately higher doses to tissues in children compared with adults, from wireless laptops and utility meters [56,57,58].

Research has linked exposure during pregnancy to adverse effects. The authors of a case-control study published in 2015 stated, "use of mobile phones can be related to early spontaneous abortions" [59]. Maternal mobile phone use during the first trimester of pregnancy may contribute to slowing or halting of embryonic development [60], possibly due to effects on membrane receptors in human amniotic cells [61]. A 2019 study of over 55,000 pregnant women and infants in four countries (Denmark, the Netherlands, Spain and Korea) linked maternal cell phone use during pregnancy with shorter pregnancy duration and increased risk for preterm birth [62].

Behavioral problems have been associated with prenatal and postnatal cell phone exposure. In five cohorts, Birks et al. found cell phone use by a pregnant woman to be associated with an increased risk for behavioral problems, particularly hyperactivity/inattention in her child [63], and Divan et al. reported behavioral problems in children up to seven years of age [64,65]. Studies of children and adolescents report possible associations of wireless technology use with addictions and depression [66], fatigue [67], altered baseline thyroid hormone levels [68], and poorer well-being [69,70]. Sage and Burgio discuss the damage from low levels of RFR to genetic material including DNA and nuclear structures in the cell, and potential mechanisms of child neurodevelopmental impairment [71].

A Yale University study found that when mice were exposed *in utero* to cell phone radiation, they had impaired memory and increased hyperactivity in adulthood [72].

Not only can RFR act along with carcinogens to promote tumor development [50], it also may synergize with toxic chemicals in other ways. For example, in a study of Attention Deficit Hyperactivity Disorder in children, ADHD was associated with mobile phone use for voice calls only in children who were also exposed to relatively high lead levels (lead is an established, potent neurotoxin) [73]. Further synergistic effects between RFR and various chemicals including nutrients (i.e., both beneficial and adverse) are described in a 2016 review by Kostoff and Lau [74].

4.4. Sperm

Three systematic reviews published from 2014 to 2016 [75,76,77] reported significant adverse effects on sperm quantity and quality, as well as DNA damage, from everyday RFR exposures. Animal studies reported testicular damage at 0.002 W/kg [78] and sperm damage at 0.024 W/kg SAR values [79].

4.5. Wi-Fi and other ambient RFR

Much of the RFR research reported thus far has focused on exposures to users of devices in close proximity (e.g., cell phones). More distant sources such as Wi-Fi access points or cell towers generally contribute less to exposures because RFR drops off quickly with distance from the source, following the "inverse square law" (levels are a quarter at twice the distance; one-ninth at three times the distance; etc.). Although exposure intensities from distant sources are usually low compared with devices in close proximity, simultaneous exposures are complex as devices connect to networks, people move around, and RFR may be reflected or absorbed by building materials, other surroundings, and inhabitants [80,81].

At any particular point in space and time, electromagnetic exposures are the sums of electrical and magnetic field vectors [7]. Of importance for health, effects (e.g., oxidative stress and consequences in tissues) may be cumulative over time, and these effects are modulated by other exposures to chemicals (nutrients as well as adverse substances) and other stressors [8]. 5G is to be deployed with multiple directional antennas, but future exposures are not well characterized [30], and less is known of future health outcomes from this technology.

In a comprehensive literature review, Pall states that "Wi-Fi causes oxidative stress, sperm/testicular damage, neuropsychiatric effects including EEG changes, apoptosis [cell death], cellular DNA damage, endocrine changes, and calcium overload," that the effects from continuous, long-term exposure may be cumulative, and that pulsed signals are more biologically active than a smooth carrier wave [82].

Impaired brain development and cognitive function, as well as addictive behaviors in children and adolescents are observed with exposure to RFR [71,81]. In a study of exposure to RFR in schools, 18 teachers wore "exposimeters" to continuously record exposures to a spectrum of RFR. Mean exposure levels varied widely according to activities in the classroom, but peak measures were up to 83,000 μW/m^2 [81]. The highest levels occurred when students were streaming video, and the lowest occurred when the teacher had a wired Internet connection in a classroom far from Wi-Fi access points and students' laptops were in airplane/flight mode [81].

Measurements of ambient RFR have been carried out in other settings, including a train station [80] and other Stockholm landmarks [83], and neighborhood surveys from a car [84]. Ambient measurements correlate moderately with personal monitoring.

In an extensive review, Dürrenberger et al. characterized RFR and emissions from infrastructure in micro-environments [85]. Exposures are typically underestimated, and experts, officials and citizens may be surprised at the differences among venues. These uncertainties make it statistically difficult to detect health effects, resulting in under-estimation of harms as well [86]. Although exposures generally meet government regulatory limits, they exceed precautionary recommendations [80]. Recent reviews of RFR assessments found higher levels in offices and public transportation [87,88].

Researchers in a Bavarian village followed a natural experiment over 18 months, when a central cell tower was installed [89]. They found dose-dependent dysregulation of stress hormones, according to peak RFR exposure measured at the doorstep [89].

Effects reported in RFR studies may be complex and non-monotonic (i.e., effects occur at lower exposure levels that do not manifest at higher levels) [48,50,90]. It is known that biological mechanisms are established whereby chemicals cause complex dose-responses, particularly for hormone-related effects (the endocrine system) [91,92].

4.6. Electromagnetic hypersensitivity (EHS)

As with other environmental exposures, some people are more susceptible (sensitive or intolerant) and overtly affected by RFR. Electromagnetic hypersensitivity (EHS) is also commonly termed electrical sensitivity, electrohypersensitivity, idiopathic environmental intolerance, or (historically) microwave sickness.

Common symptoms of EHS include headaches, cognitive difficulties, sleep problems, dizziness, depression, fatigue, skin rashes, tinnitus and flu-like symptoms [93,94]. Adverse reactions to wireless devices range from mild and readily reversible to severe and disabling, and individuals must greatly reduce their exposures to sources of electromagnetic radiation [95,96,97].

Surveys conducted in several countries at times ranging from 1998 to 2007 estimated that approximately three to thirteen percent or more of the population experience symptoms of EHS [98–101].

As well as being difficult to manage in the modern world, EHS is typically unexpected. The theory that EHS is merely a "nocebo" response – that it results from suggestion and worry over possible effects of electronic devices – is the opposite of experience. In a study of 40 people, their EHS was only recognized following a period of illness and self-experimentation [102]. Further research has confirmed that lived experience is not consistent with the nocebo hypothesis [103].

EHS is recognized as a disability and is accommodated in the U.S.

under the *Americans With Disabilities Act* [104]. Sweden recognizes EHS as a functional impairment [99]. In Canada, the condition is included under environmental sensitivities [97,105]. Legal cases for compensation, disability pensions and accommodation in various countries are discussed in Section 6.

Physicians' organizations' research, experiences, practices and statements over the years were summarized by the European Academy of Environmental Medicine (EUROPAEM) in 2016 [4]. Sensitivities vary among individuals, and symptoms may also occur with exposures outside the RFR range. The consensus of the *EUROPAEM EMF Guideline* is that the most important action for treatment and management of EHS is reduction and avoidance of pertinent exposures in locations where significant amounts of time are spent, especially in sleeping areas. Other recommended measures include a suite of healthy lifestyle measures such as nutrition, stress reduction and measures to avoid toxicants, as well as to reduce levels of toxicants sequestered in the body [4].

4.7. Rigorous systematic review of the scientific evidence, for public health, policy and regulation

As evidenced here, contributions of RFR to adverse effects on public health may be substantial [106,107]. Public policy, and safety guidelines and standards, should be based on all of the best available scientific evidence; however, there has never been a systematic review conducted according to international best practices [108] of the RFR evidence, upon which to base exposure guidelines.

Influence of biases and conflicts of interest has been documented as a serious concern for international authoritative bodies such as the World Health Organization-International Electromagnetic Fields (EMF) Project, and the International Commission on Non-Ionizing Radiation Protection [109–111]. The same is true for the national authorities in Australia [112], Canada [113–115], the European Commission [116], the United Kingdom [117] and the U.S [118]. Bias in original scientific studies is evident in that studies funded by industry are less likely to identify adverse effects than those that are independently funded, and even less likely to conclude that adverse effects exist [119–121].

An important step towards resolution of the adequacy of guidelines and standards to protect public health, as well as policy and practical responses for individuals who experience EHS, would be a thorough systematic literature review conducted by independent, knowledgeable specialists. This would examine all of the RFR literature dating back to the identification of health concerns with the development and deployment of radar during World War II, including the studies in the 1971 review by Dr. Zorach Glaser [122].

Key features of this type of review include that all steps and findings must be transparent, such as bibliographic search methods, study selection, data extraction and meta-analyses, quality assessment and the weight of evidence analysis [108].

5. Environmental impacts of cell tower and radiofrequency radiation

Built and natural environments are interconnected. Biological systems are integrated, complex and operate using minute electrical charges combined with precise chemical signals. These mediate complex functions such as development, reproduction and cognition. Recent research has demonstrated adverse effects of radiofrequency radiation (RFR) on environments and wildlife, including birds, amphibians, insects, fish, mammals and plants [123–125]. For example, trees near cell towers can become visibly unhealthy on the side facing a cellular antenna, and can die prematurely [126].

A diverse array of species depends upon the Earth's low-level magnetic field to navigate for migration, homing, breeding, foraging and survival. RFR can have significant long-term impacts on the natural environment via disruption of normal positioning and orientation abilities as well as other complex cellular and biologic processes. Incremental effects may be only slowly recognized as species and ecosystems decline.

Small deposits of the iron-containing mineral magnetite act as magnetoreceptors to sense the Earth's magnetic field in a variety of organisms, including bacteria, insects, fish, birds and mammals [127–129].

Some bird species are strongly influenced by the low-intensity magnetic fields of the Earth for directional reference. Newer studies suggest that light-dependent cryptochrome photo receptors in birds' eyes are also sensitive to magnetic forces, and communicate with the brain [130,131].

RFR can interfere directly with magnetoreception in birds, disabling their avian magnetic compass [132]. A series of double-blinded studies replicated over several years demonstrated that migratory European robins lost their ability to orient and navigate in a city with high background "electromagnetic noise" and broadband frequencies [133]. Effects can be complex, as illustrated by findings that some birds can be more sensitive to weak broadband than to stronger fields [134,135].

Bees use magnetite crystals in their abdomens for navigation [136]. This sensory modality can be disrupted by electromagnetic fields, causing a loss of colony strength [137–140]. Scientists are increasingly concerned about the impacts of wireless radiation on the worldwide decline of domestic bees and colony collapse disorder [141,142]. Other insects are also adversely affected by RFR [142–145].

Review articles indicate that the weight of evidence is that RFR acts as an environmental toxin with ecosystem-wide harm from increasing ambient RFR emitted by cell towers and other RFR infrastructure [146–152].

6. Liability

Some industry liability insurance providers do not provide coverage against adverse health effects from RFR. Lawsuits for RFR health-related conditions are underway, and some have been successful in different countries.

6.1. Insurance industry and liability related to radiofrequency radiation

Insurers have declined to provide coverage to wireless product manufacturers and U.S. mobile operators for health damages from their products and networks since the early 2000s [153]. Insurers often exclude or limit coverage for the risk from electromagnetic fields (EMFs) posed by commercial general liability policies, decline policyholders in the wireless industry, and only provide coverage via pollution liability policy enhancements.

Insurance authorities also address the risks of electromagnetic fields. In 2014, the Swiss RE report *New emerging risk insights* listed the potential impact of the "Unforeseen consequences of electromagnetic fields" as "High" and examined further incremental risk associated with smart cities [154]. In its 2019 update, Swiss Re identified the top two emerging risks to be "digital technology's clash with legacy hardware, and potential threats from the spread of 5G mobile networks" [155].

In 2010, the Emerging Risk Team of Lloyds issued a white paper [156] indicating that the potential risks to insurers from health damage claims associated with cell phones and wireless radiation are comparable to those posed by asbestos. The 2013 Lloyds Risk Index lists "harmful effects of new technology" as an increasing environmental risk [157].

Some corporate insurance policies feature a general exclusion section that explicitly prohibits liability for injury or property damages from electromagnetic fields. This is considered to be a standard across the North American insurance industry [158].

Insurance company policies will often define electromagnetic radiation as a "pollutant." According to the AT&T Mobile 2012 Insurance policy, "Pollutants" mean: "Any … artificially produced electric fields,

magnetic field, electromagnetic field, sound waves, microwaves, and all artificially produced ionizing or non-ionizing radiation and waste." [159]. Policy enhancements can be purchased to cover environmental pollutants, which include EMFs [160,161].

The Austrian Worker's Compensation Board (AUVA) commissioned the Vienna Medical University to research effects of cell phone radiation on the brain, immune system, DNA and proteins, and published a series of reports that present the research evidence and conclude by recommending precautions to reduce exposure [162,163].

6.2. Summary of 10 K reports

Publicly traded companies issue annual 10-K reports to the U.S. Securities and Exchange Commission, summarizing the company's financial performance and status. Mobile operator reports identify potential liabilities for health damages from exposure to wireless devices as a risk, and provide no assurances that their products or equipment will be safe in future years.

Crown Castle states in their 2017 Annual Report [164], "If radio frequency emissions from wireless handsets or equipment on our communications infrastructure are demonstrated to cause negative health effects, potential future claims could adversely affect our operations, costs or revenues."

Verizon's 2017 Annual Report [165] states, "… our wireless business also faces personal injury and wrongful death lawsuits relating to alleged health effects of wireless phones or radio frequency transmitters. We may incur significant expenses in defending these lawsuits. In addition, we may be required to pay significant awards or settlements."

6.3. Lawsuits related to electromagnetic fields

In the U.S., the first cell phone cancer case was filed in 1992 and was followed by a series of cases that were either settled by confidential resolutions or dismissed due to lack of evidence or lack of authority of the court [166]. At the time of writing, there are thirteen active consolidated cases with defendants alleging their brain cancers were from cell phone use [167]. In 2017, Italy's highest court recognized a causal link between development of a brain tumor and cell phone use, and awarded social security payments [168].

Internationally there are several lawsuits related to cell phones and cancer and disability from EMF exposures. For example, Australian [169] and Spanish [170] courts have awarded disability to workers claiming sensitivity to electromagnetic radiation.

In January 2019, an Italian court ordered the government to launch a campaign to advise the public of the health risks from mobile and cordless phones [171].

7. International actions to limit public exposure to RFR

Some international governments have passed legislation (Table 1), and health and environmental authorities in numerous countries, regions and cities have issued recommendations (Table 2) to reduce exposure of the public to radiofrequency radiation (RFR). Measures frequently focus on children's vulnerabilities [172], identifying "sensitive areas" with stricter exposure limits where the young sleep, play and learn.

5G, the next generation of wireless technology, will utilize frequencies presently in use, plus higher frequency millimeter waves not previously used for commercial telecommunications. Regional governments, such as the Cantons of Geneva, Vaud and Neuchâtel in Switzerland, are issuing decrees calling for moratoriums on the rollout of 5G technology until the health effects are better understood [173–175].

7.1. Regional U.S. Guidelines and recommendations to limit RFR exposure in schools

In addition to national policies to reduce children's EMF exposures, several authorities in the U.S. have issued guidelines for schools. In 2014, the Collaborative for High Performance Schools (CHPS) [189], the leading organization for healthy schools in the U.S., first published recommendations to minimize exposure to both Extremely Low Frequency (ELF) magnetic fields and RFR. Criteria for "Low-EMF Best Practices" include:

- providing a wired local area network (LAN) for Internet access throughout the school;
- disabling all wireless transmitters on all devices;
- ensuring that all laptops or notebooks have an Ethernet port and a single physical switch to disable all wireless radios;
- providing easily accessible hard-wired phones for teacher and student use;
- prohibiting the installation or use of DECT cordless phones; and
- prohibiting the use of cell phones and other personal electronic devices in instructional areas.

In 2016, the New Jersey Educational Association [190] and the Maryland Children's Environmental Health and Protection Advisory Council (CEHPAC) [191] also issued recommendations to reduce RFR in school classrooms, including, "if a new classroom is to be built, or electrical work is to be carried out in an existing classroom, network cables can be added at the same time, providing wired network access with minimal extra cost and time."

Measures to reduce exposures regarding personal devices are listed in the Appendix.

8. Recommendations for the building industry

Rapidly evolving technology is resulting in an evolution of building systems, moving to integration of air quality control, power management, surveillance and access, communications and data management, etc. in "smart" buildings. Although wireless "Internet of Things" may be popularized as central to "smart" infrastructure and conveniences, key features can readily be physically connected non-wirelessly. Sinopoli detailed essential elements of design, construction (installation of cables/wiring), integration and operation of networked systems to improve indoor environments and function, and achieve efficiencies in indoor spaces [192].

Electromagnetic interference is another reason to minimize radiofrequency radiation RFR [193]. It can degrade operation of wireless systems (e.g., Wi-Fi), and sensitive electronic equipment (wired or wireless) such as for entertainment recording or medical applications. Addition of cell towers in proximity to unshielded areas (indoors or outdoors) can also cause signal interruptions and static. In the extreme, wireless systems can be shut down by malicious attack with strong signals "drowning out" signals on designated frequencies.

Health care policies have evolved to protect operation of essential equipment. Mobile phones were initially forbidden in hospitals due to risks of interference with operation of sensitive equipment. Based on limited study, it is now recommended that wireless devices be kept at a distance from sensitive equipment (e.g., in intensive care units [ICUs]) [194]. Today, wireless access for patients and the public is often provided in hospitals, and wireless devices are common in healthcare [195]. There is no evidence of clinical benefit, and reviews did not investigate potential clinical harms [195].

For any systems that are not "wired," architects, builders, owners and inhabitants all must operate within constraints of regulated RFR exposure levels. RFR exposure limits vary among jurisdictions, with the highest permitted personal exposures in the U.S.A. and Japan. Many countries adhere to the International Commission on Non-Ionizing

Table 1
Examples of national legislation limiting RFR.

Year	Country and Reference	Legislation
2016	French Polynesia [176]	Banned marketing of cell phones to children. Prohibited wireless in nursery schools.
2015	France [177]	Banned Wi-Fi from nursery schools. Decreed that in schools Wi-Fi be turned off as default, unless the teacher uses it for specific instruction. Wi-Fi hotspots must be labeled.
2014	Korea [178]	Mandated SAR labeling on cell phones and portable devices. Public health recommendations to reduce exposure to cell phone radiation.
2013	Belgium [179]	Banned marketing of cell phones to children below age 14. Phones designed for children below age 7 years are prohibited from sale.
2012	India [180]	Limited RF-EMF exposure levels from cell antennas to 1/10th of International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines. Required SAR labeling on phones.
2012	Greece [181]	Forbade installation of mobile phone base stations on the premises of schools, kindergartens, hospitals or eldercare facilities.
2010	France [182]	Required that cell phones be sold with a headset and recommendation to limit exposure to the head. Cell phone advertising aimed at children below age 14 years was banned.

Radiation Protection (ICNIRP) recommended guidelines for power flux density, electrical fields and SAR for various frequencies [196]. Exposure limits range widely, for example in terms of power density at 900 MHz, as summarized in Fig. 3.

8.1. Building guidelines for lower electromagnetic field (EMF) exposures

Green building standards for occupants' health put great emphasis on indoor air quality, and the electromagnetic characteristics of the indoor environment are beginning to gain more widespread attention. This is exemplified by the aforementioned CHPS "Low-EMF Best Practices" in the U.S [189].

In Austria, Germany and Switzerland, however, electromagnetic fields and radiation exposures have long been a green building consideration. In Germany, the first precautionary exposure guideline for sleeping areas (SBM-2015) [28] was issued by Baubiologie Maes in cooperation with the Institute of Building Biology and Sustainability (IBN) in 1992. Based on thousands of electromagnetic assessments, radiofrequency radiation (RFR) levels in the bedroom below 0.1 μW/m^2 are considered "no anomaly." RFR levels above 1000 μW/m^2 (1 mW/m^2) are considered an "extreme anomaly."

The Total Quality Building Assessment Tool (TQB) is a widely used green building rating system [199], addressing a broader range of parameters than the Leadership in Energy and Environmental Design (LEED) rating system [27]. Since its inception in 2001 the TQB tool has included low-intensity EMFs and radiation – both low-frequency alternating magnetic fields and RFR. The TQB awards points in the planning and final testing stages for low levels of RFR.

The European Academy for Environmental Medicine (EUROPAEM) EUROPEAM EMF Guideline 2016 for the prevention, diagnosis and treatment of EMF-related health problems and illnesses [4] details recommendations for precautionary threshold electromagnetic exposure levels, including for RFR.

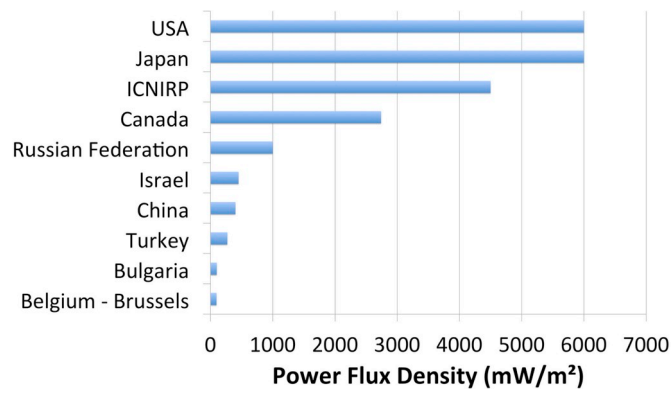

Fig. 3. International RFR power flux density exposure limits at 900 MHz [197,198].

To put these recommendations into context, the precautionary thresholds fall somewhere between the low natural background level and official exposure limits (Fig. 3). For comparison, Table 3 summarizes prudent, precautionary recommendations of European specialists.

The guiding principle of "as low as reasonably achievable" (ALARA) was introduced as early as the 1950s to protect against ionizing radiation [200] and holds true for many toxicants to the present day [91], including RFR [201]. RFR levels in indoor environments can be minimized by integrating the principal of ALARA (minimize emissions and exposures, maximize distance and use protection) [202] into selection of the building location, design and materials, as well as choices of electrical, monitoring, control, surveillance and other systems and services.

Table 2
Examples of national policies, public health advice and medical organization recommendations.

Year	Organization and Reference	Advice and Recommendations
2017	Athens Medical Association [183]	Sixteen recommendations to reduce human exposure to wireless radiation
2016	France - National Decree [184]	Reduced EMF exposure of workers, especially pregnant women
2016	US - American Academy of Pediatrics [185]	Ten recommendations to reduce exposure to cell phone radiation
2015	Cyprus National Committee on Environment and Child Health [186]	Public service videos and brochures for families about how to reduce cell phone and wireless exposure
2009, 2015	Finland - Radiation and Nuclear Safety Authority [187]	Recommendations to reduce RFR exposure, especially of children
2011	Parliamentary Assembly, Council of Europe [188]	"The potential dangers of electromagnetic fields and their effect on the environment" recommends As Low As Reasonably Achievable (ALARA), awareness, precautionary approaches, transparency, research, etc.
2010	France - National Public Health Agency [182]	An awareness campaign about ways to reduce RFR exposure

Table 3
Precautionary guidance RFR exposure levels [4,199].

		Exposure to 900–1800 MHz RFR (mW/m^2)
TQB Tool	Planning stage	
	10 points (best)	≤1
	5 points	≤3
	0 points	> 3
	Final stage	
	10 points	$S \leq 0.01$
	8 points	$0.01\ mW/m^2 < S \leq 0.1$
	6 points	$0.1\ mW/m^2 < S \leq 1$
	4 points	$1\ mW/m^2 < S \leq 3$
	0 points	> 3
EUROPAEM 9001800 MHz		
	Daytime	0.1
	During sleep	0.01
	Sensitive Populations	0.001
Natural Background		0.000000001

8.2. Strategies to eliminate or minimize RFR exposures from sources within buildings

As exemplified in section 8.1, engineers, architects, designers and planners have a unique opportunity to create healthier living, learning and work environments by reducing use of wireless technologies and thereby reducing levels of RFR. Although it is simpler, preferable and less expensive to implement RFR-free options during the initial design and construction stages, existing buildings represent many opportunities for improvements.

8.2.1. Connect necessary technologies with cables

An important first step to minimize levels of RFR within buildings is to eliminate indoor sources of RFR, and to connect all technologies via wire or fiber cable ("wired").

Consider alternative approaches to wireless technology. Recommendations include:

- Neighborhood infrastructure with cable access for high-speed, wired telephone and Internet;
- Within buildings use cables, preferably shielded, in Local Area Networks (LAN) to provide wired access points for all networking and data transmission, including wired connections for modems, routers, Internet and media; lighting, heating, ventilation, air conditioning (HVAC), thermostats and humidistats; surveillance and security systems; fire detection and response (e.g., sprinklers); pool equipment such as pump and treatment controls, etc.;
- Install easily accessible wired (not cordless) phones and prohibit installation and use of cordless phones;
- Throughout the building, provide connections to hardwired CAT6 or CAT7 Ethernet cables, preferably shielded, to service devices such as computers, tablets and other devices. Use wired peripherals and accessories. Ensure that all wireless features are turned off or disabled;
- Install wired RJ11 phone jacks for corded and landline telephones; and
- Use analog, non-transmitting utility (water, electricity, gas) meter options, that do not transmit data wirelessly.

8.3. Strategies to minimize the RFR exposures from external sources

8.3.1. Building location and landscaping

To achieve very low RFR levels, new buildings may be located in a low-RFR environment, for example at a distance from cell towers, radio and TV broadcast towers, and radar sites (e.g., airports). Evaluate the proposed location with professional grade RFR equipment to determine ambient RFR levels and sources. Sites in valleys may be at least partially protected from regional sources of RFR by surrounding hills, as may underground structures by intervening earth that absorbs RFR, depending upon composition and moisture level [203]. Conductivity and permittivity of soil increases with moisture content [204]; MW radiation is strongly absorbed by water.

Vegetation, with its significant water content, will absorb some RFR. While foliage of tall deciduous or evergreen trees may present challenges to wireless service providers, absorption of RFR from nearby antennas may also harm vegetation [126].

8.3.2. Building materials and shielding

RFR may be either reflected or absorbed by building materials, and there is a continuum of how opaque building elements are to RFR [204]. Shielding with highly absorbing or conductive materials can be very effective to reduce RFR originating from outdoors sources [205].

Many building materials such as wood and wallboard are largely transparent to present day RF signals, but research is intensifying on RFR-absorbing materials and fabrics that contain metals or carbon based substances (e.g., nanotubes) [206,207]. Construction materials are less effective barriers to RFR in the MHz and lower GHz frequency ranges, as currently used for cell phones, than for higher GHz frequencies planned for 5th generation (5G) technologies [208].

Absorption rather than reflection offers clear advantages for protection from RFR, and considerable relevant research has been devoted to materials that absorb radar [205]. Thick layers of dense building materials such as concrete offer some potential to absorb RFR and thereby reduce levels, particularly in the GHz range. Early research indicating high attenuation [209] was not precisely replicated with drier samples.

Conductive materials must be used with care and caution because reflections may result in unanticipated exposures. Totally enclosing a space with reflective materials (e.g., metal) results in a "Faraday cage." Radiation from sources within the "cage" reflects from one surface to another and this can result in higher local levels than would be the case if RFR was transmitted or absorbed by structural materials and furnishings.

To shield against incoming RFR from cell antennas, Wi-Fi networks and radio broadcast towers, shielding may be integrated across the entire building envelope or selected rooms or zones of a building.

Low-E windows coated with a transparent layer of metal oxides (developed to reflect infrared to retain heat in buildings and reflect ultraviolet light from the outdoors) and metals reflect RFR. Exterior shielding may be achieved with metal cladding/roofing, metal window and door frames, metal or metal-clad doors, low-E windows, metal screens, RF window film, and fine metal mesh or radiant barrier foil integrated into the building envelope. Further options indoors include high quality carbon-based shielding paints or fine metal mesh, and RF-shielding drapes/sheers. Conductive shielding materials including paint must be electrically connected and properly grounded.

It is essential to recognize that within shielded spaces, devices must have all wireless functions turned off. Poor network connections for cell phones will result in stronger RFR signals from the device itself, with potentially four-fold higher exposure to the user [210], and reflections from metal shielding may result in yet higher exposures. Thus, prominent explanatory safety notices are necessary to ensure that all cell phones are "off," set to "airplane mode," or are left outside of the low-RFR shielded zone. Options to meet occupants' needs include provision of accessible corded landline telephones to which cell phone calls can be forwarded, and provision of wired connections for devices.

Whatever options are used to achieve low RFR levels, it is necessary to verify final results with measurements using an RFR meter. RFR from equipment and exterior sources, along with reflections, and interactions with conductive infrastructure can result in complex, unanticipated patterns of electromagnetic fields, including hotspots [193,208]. Periodic checks are necessary to ensure that additional equipment,

furnishings or modifications, indoors or outdoors have not increased RFR levels.

Each make and model of RFR meter or measurement instrumentation has different specifications. To confirm the effectiveness of an RFR meter, obtain a third-party calibration report from a certified testing facility.

8.3.3. Partial RFR-Reduction measures for internet connectivity in buildings

In homes, schools, and workplaces, the installation and exclusive use of wired Internet access and electronic communication among devices mitigates the RFR emissions from internal network systems.

During any time that a wireless function is enabled, on stationary or mobile equipment, routine signals to maintain connections will expose building occupants to RFR, whether or not the device is actually being used.

In situations where decision makers decide not to hardwire a building immediately and instead continue with wireless connectivity, some partial measures may partially reduce unnecessary exposure. Importantly, these partial reduction steps do not equate with complete RFR mitigation, do not ensure safety for occupants, and do not reduce liability.

Recommendations include:

- Connect routers to a power source using a timer, to power off when not routinely in use, such as at bedtime;
- Wireless routers and access points should have an easily accessible switch to turn them off when not in use;
- Choose routers that can accommodate wired input, equipped with an accessible on/off switch for wireless features, and use a wired connection to a wired modem, to provide Internet connection when the wireless function is turned off;
- Avoid modems that also act as public “hot spots;”
- Do not install wireless access points near bedrooms or other highly or frequently occupied spaces;
- Clearly label wireless access points and areas where wireless antennas are in use;
- Use wired connections for HVAC monitoring and control, lighting, security and other fixed monitors and controllers;
- For improved security and lower carbon footprint, as well as reduced RFR, access data and controllers via a wired connection;
- If a wired analogue utility meter is not an option, mount the wireless meter at a distance, shield appropriately and direct signals to where they are read. Locate wireless meters away from high-use areas, particularly bedrooms; and
- If the building is mostly shielded, but has an unshielded zone for wireless device use, ensure that there is signage informing people: 1) of the RFR exposures along with wireless access (and alternatives onsite); and 2) the need to have all wireless functions turned off in shielded zones.

Implementation of partial measures will continue to expose occupants to RFR at levels associated with adverse effects. Measures such as turning off wireless features when not in use still result in RFR exposures, are not ALARA, and ideally will only be used in the interim while wiring plans are being developed and implemented.

8.4. Sensitive and vulnerable individuals

All of the above and more may need to be implemented to reduce RFR adequately in indoor and outdoor environments, to accommodate sensitive individuals. This will often require engaging an EMF expert, because the behavior of electromagnetic fields, currents and radiation is complex and difficult to predict. Sensitive individuals must be consulted throughout the duration of any renovation or building project, because individuals may react differently to various electromagnetic exposures. These individuals may also be sensitive to indoor air quality, so they must be involved in selection of materials for construction or retrofitting [2].

8.5. Challenging the business case of wireless systems

Not only are multiple risks invoked by choices of wireless instead of wired technology, there are many advantages to wired solutions.

Wireless networks [29,211]:

- continue to be about 100 times slower than wired systems;
- are unreliable, and more prone to both latency and delay issues;
- consume significant amounts of energy – more than wired – and are not sustainable;
- increase the points of vulnerability; and
- increase the security and privacy risks to personal and business data.

Some companies are cautioning that deployment of wireless 5G and beyond will be hampered by current regulatory power density exposure limits [212,213].

9. Discussion and conclusion

The breadth of peer-reviewed scientific research demonstrating biological effects of radiofrequency radiation (RFR) below current guidelines and standards highlights the need to further develop and codify pertinent building technology standards and guidance. Public health risks, accessibility needs, industrial liability and international precautionary actions indicate that RFR is an important performance parameter in building science.

Parallel with rapid innovation in wireless technologies, and the increasing RFR both inside and outside building structures, building science must also innovate to include alternative, physically connected technologies and systems. This is important to achieve accessibility and a building's success. Ensuring that the health and safety of occupants are not compromised requires those in the building science professions to develop and apply needs and means assessments, as well as best practices for methods and models for communications, with RFR wireless technology as a less-preferred option.

Research and knowledge transfer are needed to develop, publish, and encourage compliance with explicit directions for the integration of wired communications technologies in the design, planning, engineering, construction, operation and life cycle of a building.

Building science has embraced ecology and sustainability as core tenets in building performance. Currently, modern technologies minimizing RFR exposures offer an under-addressed opportunity for “smart” buildings also to be healthy – for their occupants, and for natural and built environments.

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Appendix

General Safety Tips to Reduce Radiofrequency Radiation (RFR) Exposure from Personal Devices

- Keep cell phones away from the head and body, and keep wireless devices at a distance, and off of laps.
- Make only short or essential calls on cell phones.
- Use text messaging instead of voice calls whenever possible.
- As much as possible power off phones and personal digital devices, or set on airplane mode with Wi-Fi, Bluetooth, Data, Mobile Hotspot and Location off.
- Avoid sleeping next to cell phones or wireless devices; power them

off at night. If a cell phone must be used as an alarm clock, turn the phone to airplane mode, or use a separate battery-powered clock.
- Keep non-prescription electronics out of bedrooms. If you depend upon medical devices with wireless functions, check how often they may be set to "airplane mode," and ask your health care provider about adequate alternatives that do not emit RFR.
- Avoid charging phones and devices near beds.
- Use a corded (not cordless) home phone (wired [not wireless] VoIP or landline) whenever possible, especially for long voice calls.
- Pre-download videos and music rather than streaming.
- Minimize the number of apps running on wireless devices.
- Choose wired Internet connections instead of wireless systems, whenever possible. Provide wired Internet connections for others.
- If Wi-Fi cannot be entirely eliminated, put the Wi-Fi router on a timer to turn off when not needed (especially while sleeping).
- When digital devices are connected with wired Internet connections, turn off the Data, Wi-Fi and Bluetooth (in device settings) and turn off the Wi-Fi on the router.
- Request wired options and provide them to others, such as for computers, laptops, tablets, printers, gaming consoles and handsets, mouse, keyboards, video cameras, speakers, headphones, microphones and other accessories.

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Genetic susceptibility may modify the association between cell phone use and thyroid cancer: A population-based case-control study in Connecticut.

Luo J[1], Li H[2], Deziel NC[1], Huang H[1], Zhao N[3], Ma S[4], Ni X[5], Udelsman R[6], Zhang Y[7].
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Highlights

- The interaction between cell phone use and genetic variants on thyroid cancer was investigated in this study.
- When some genetic variants were present, cell phone use was significantly associated with thyroid cancer.
- The association increased when cell phone use duration and frequency increased.
- Genetic susceptibility may modify the association between cell phone use and thyroid cancer.

Abstract

Emerging studies have provided evidence on the carcinogenicity of radiofrequency radiation (RFR) from cell phones. This study aims to test the genetic susceptibility on the association between cell phone use and thyroid cancer. Population-based case-control study was conducted in Connecticut between 2010 and 2011 including 440 thyroid cancer cases and 465 population-based controls with genotyping information for 823 single nucleotide polymorphisms (SNPs) in 176 DNA genes. We used multivariate unconditional logistic regression models to estimate the genotype-environment interaction between each SNP and cell phone use and to estimate the association with cell phone use in populations according to SNP variants. Ten SNPs had $P < 0.01$ for interaction in all thyroid cancers. In the common homozygote groups, no association with cell phone use was observed. In the variant group (heterozygotes and rare homozygotes), cell phone use was associated with an increased risk for rs11070256 (odds ratio (OR): 2.36, 95% confidence interval (CI): 1.30-4.30), rs1695147 (OR: 2.52, 95% CI: 1.30-4.90), rs6732673 (OR: 1.59, 95% CI: 1.01-2.49), rs396746 (OR: 2.53, 95% CI: 1.13-5.65), rs12204529 (OR: 2.62, 95% CI: 1.33-5.17), and rs3800537 (OR: 2.64, 95% CI: 1.30-5.36) with thyroid cancers. In small tumors, increased risk was observed for 5 SNPs (rs1063639, rs1695147, rs11070256, rs12204529 and rs3800537), In large tumors, increased risk was observed for 3 SNPs (rs11070256, rs1695147, and rs396746). Our result suggests that genetic susceptibilities modify the associations between cell phone use and risk of thyroid cancer. The findings provide more evidence for RFR carcinogenic group classification.

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Background and Facts Documenting PhoneGate and Our Call for Congressional Action

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Introduction to PhoneGate

The international NGO, PhoneGate Alert Association, as well as Environmental Health Trust and other public health organizations have documented evidence that for nearly 30 years, manufacturers have been placing cell phones on the market under deceptive testing conditions, posing a risk to the health and safety of billions of users.

This new public health scandal has a name: "PhoneGate." The FCC's decades old cell phone test method in use today allows phones to pass pre-market regulatory exposure tests despite the fact that the very same phones would not pass if the tests ensured phones were tested the way they are used - in positions of body contact as when worn and used in pockets or tucked into waistbands or bras.

The tests used by manufacturers and regulators have not taken into account the real world conditions of use in the calculation of the SAR (Specific Absorption Rate) value; i.e. the metric used to evaluate microwave radiation exposure from cell phones to the human body. Real world conditions include contact with the body when phones are carried or used in shirt or pants pockets or tucked into bras and waistbands.

Despite the fact that phones are not tested in positions of body contact, cell phone companies still advertise phones in positions that result in consumers thinking phones are safe in any position.

This issue must be investigated in light of the deployment of 5G networks in the United States which will include billions of new interconnected devices in addition to 5G connected cell phones. How can we allow all of these new devices on the market when they are not pre-market tested for cell phone radiofrequency SAR compliance the way we use them- in close body contact?

Deception by cell phone manufacturers and serious shortcomings of regulators

In the United States cell phones are tested for compliance with radiofrequency SAR limits using test protocols which allow the phone to be placed at a distance of 5 to 25 mm from the simulated body "phantom." Phones are not required to be tested in positions of body contact as they are used by consumers.

In addition, the U.S. government does not perform independent cell phone compliance testing, allowing each manufacturer to submit their own SAR testing results to the FCC. Manufacturers in the US and worldwide do their own testing on an "honor system."

Recent investigations find manufacturers' test reports differ from independent testing and many phones exceed regulatory limits when tested at body contact.

> In August of this year, the Chicago Tribune published the results of their investigation into the SAR levels of the top-selling U.S. phones when tested held 5-15 millimeters away from the testing device as FCC exposure testing guidelines allow:
>
> "*This test, which was…conducted according to federal guidelines at an accredited lab, produced a surprising result: Radiofrequency radiation exposure from the iPhone 7 — one of the most popular smartphones ever sold — measured over the legal safety limit and more than double what Apple reported to federal regulators from its own testing.*
>
> *The Federal Communications Commission, which is responsible for regulating phones, states on its website that if a cellphone has been approved for sale, the device "will never exceed"*

the maximum allowable exposure limit. But this phone, in an independent lab inspection, had done exactly that."

Phones were additionally tested held 2 millimeters away from the testing device to simulate the way phones are typically used against the torso (as in shirt and pants pockets), and the results were even more alarming:

> *"The 2-millimeter distance was chosen to estimate the potential exposure for an owner carrying the phone in a pants or shirt pocket. Under those conditions, most of the models tested yielded results that were over the exposure limit, sometimes far exceeding it.*
>
> *At 2 millimeters, the results from a Samsung Galaxy S8 were more than five times the standard."*

Excessive radiation levels have been well documented by the Government of France

The French government French National Frequencies Agency (ANFR) has tested hundreds of cell phones for radiation levels since 2012. However, unlike regulatory compliance tests, the ANFR tests were performed with the phone in several positions, including at body contact. The results were not publicly known until 2016 after pressure from legal actions of French physician Dr. Marc Arazi and the PhoneGate Alert Association. At this time, the SAR test data on over 454 cell phones has been released.

These tests revealed that 90% of cell phones tested in 2015 exceeded regulatory limits when tested at body contact. In fact, the *majority* of tested phones exceed the SAR "on the body" value. These results were kept secret from consumers. The data can be found here.

Although the U.S. has stricter mobile phone radiofrequency compliance limits than Europe, we expect most of the U.S. phones would exceed FCC standards when tested in body-contact positions. In fact, when the ANFR data was analyzed using US FCC test protocols the excesses were as high as 11 times.

Regulatory timeline of FCC's failure to provide oversight regarding consumers' phone use in pockets – manufacturers are selling phones that are not compliant with exposure "safety" guidelines

From the 1970s to the 1990s, the U.S. Environmental Protection Agency (EPA) was researching and developing radiofrequency radiation (RFR) limits. In 1996, just as the EPA was set to release their Phase 1 of safety limits, the EPA's RFR efforts were defunded, halting all EPA research. That year the U.S. Federal Communications Commission (FCC) adopted RFR exposure limits based largely on limits developed by industry/military connected groups (ANSI/IEEE C95.1-1992 and NCRP's 1986 Report). Cell phone test protocols to ensure compliance with the limits used, and still use, simulated body "phantoms" representative of a large adult male and more importantly position the phone at a separation distance from the body.

The most recent U.S. federal hearings on cell phones were over a decade ago. Notably, the issues we are raising today were brought to light. For example, Dr. Devra Davis presented the fact that manufactures state in fine print that consumers should maintain a distance from the device in the 2009 Senate Appropriations Committee Hearing "Health Effects of Cell Phone Use."

In the 2008 hearing "Health Effects of Cell Phone Use" of the US House Oversight and Government Reform Subcommittee on Domestic Policy, FCC's Julius Knapp was asked about wireless devices such as routers in the home, and he responded that, "*Generally, there are two things that reduce any risk from those kinds of products: the lower power level and the separation. So we don't have those products up against our bodies.*" However, people are unaware that wireless devices, including cell phones, should not be used directly against their bodies.

Following these hearings and the 2011 WHO IARC classification of radiofrequency as a "possible" human carcinogen, Representatives Henry A. Waxman, Anna G. Eshoo and Edward J. Markey requested the U.S. Government Accountability Office (GAO) update information related to mobile phone health effects and regulatory issues related to compliance with the radiation limits. In turn the 2012 GAO report directed the FCC to review the human exposure cell phone radiation limits and to update their cell phone testing protocol because they found it allowed for consumers to receive SAR levels that possibly exceed the "on the body" exposure guidelines.

FCC takes no action on the recommendations of the US Government Accountability Office

In 2013, the FCC opened a proceeding and received over one thousand comments and research citations from scientific and medical experts, consumer advocates and concerned citizens. (ET Dockets No. 13-84 and No. 03-137). In these past seven years, the FCC has taken no action on the proceeding to re-evaluate the 23 year old exposure testing and guidelines…until the release on December 4th, 2019 of their formal proceeding to terminate their review and maintain the status quo.

In 2018, the GAO had updated the status of their 2012 recommendations to the FCC as "Closed – Not Implemented."

The FCC and FDA have been informed, but fail to take action

In March 2018, Dr. Arazi, president of the PhoneGate Alert Association, and Dr. Devra Davis, President of the Environmental Health Trust, jointly addressed a letter to the FCC, asking for a revision of the 1996 standards, taking into account the documentation from France showing limits are exceeded "on the body" contact positions.

The FCC still has not replied to this letter.

Organizations have written the FCC and FDA for years prior. For example, the FDA acknowledged the findings showing violations of regulatory limit at body contact in the French cell phone tests when Theodora Scarato communicated with the FDA**.**

The FCC refuses to correct their faulty cell phone testing protocol that allows consumers to be exposed to RF radiation that exceeds federal "safety" limits – declares that people should use belt clips and holsters to keep the phone away from their body

On December 4th, the FCC released a formal proceeding stating, "*Even though some parties claim that the RF exposure evaluation procedures for phones should require testing with a "zero" spacing – against the body – this is unnecessary.*" The FCC's justification for maintaining their 23 year-old, obsolete exposure testing procedures is quoted below:

> *"We also decline to revisit our RF exposure evaluation procedures for consumer portable devices, especially phones. Current evaluation procedures require consumer portable devices to be tested…at a separation distance of up to 2.5 centimeters (about one inch) from the body* ***to represent phone use in other ways****".* [46]

The FCC's footnote makes reference to an FCC document that describes the testing protocol for cell phones when simulating use directly against the torso. Exactly what are the "other ways" of using a cell phone mentioned to justify manufacturers testing their phones up to 1 inch away from the body? Why would the FCC allow this separation distance at testing INSTEAD of requiring that phone manufacturers test them with no separation distance to more accurately simulate typical use directly against the body as in a pants or shirt pocket?

The referenced FCC document states,

> "*This distance is determined by the handset manufacturer according to the typical body-worn accessories users may acquire at the time of equipment certification, but not more than 2.5 cm, to enable users to purchase aftermarket body-worn accessories with the required minimum separation….****Devices that are designed to operate on the body of users…without requiring additional body-worn accessories*** *must be tested for SAR compliance using a conservative minimum test separation distance ≤ 5 mm to support compliance.*"

And, the "body-worn accessories" that manufacturers claim their customers must use to keep the radiating phones at the "as-tested" distance from their bodies?.... From the FCC's own testing protocol, ***"for example, beltclips and holsters for cellphones"***.

How many consumers under the age of 60 still use beltclips and holsters to keep their cell phones up to an inch away from their bodies? And, none of the most popular cell phones sold today provide their users these required "body-worn accessories" nor do they warn their customers about the danger of carrying or using their phone closer to the body than the separation distance used at testing.

The FCC proceeding also states*:*

> *"…our existing exposure limits are set with a large safety margin, well below the threshold for unacceptable rises in human tissue temperature. Thus, even if certified or otherwise authorized devices produce RF exposure levels in excess of Commission limits under normal use, such exposure would still be well below levels considered to be dangerous, and therefore phones legally sold in the United States pose no health risks."*

In the above FCC statement, the FCC provides no documentation as to what the "safety margin" is or what the "levels considered to be dangerous" are.

The FCC's testing regulations should simply ensure compliance with their existing exposure "safety" limit and require that phones be tested held directly against the body with no separation, rather

than point to unknown "dangerous" levels to justify their reckless decision to allow cell phones to continue to be tested with up to a 1 inch separation distance.

The FCC is failing in its regulatory duties

The FCC is failing in its regulatory duties to protect consumers and instead is setting policy to protect the cell phone manufacturers whose phones exceed the federal safety exposure guidelines by over 500% in some cases when tested as consumers are using them: directly against the body in shirt and pants pockets and tucked into waistbands and bras.

The world-wide scientific debate continues regarding the potential serious public health impacts of wireless exposure

As you are aware, the cell phone industry is in the process of rolling out the new, untested 5G wireless technology while the world-wide scientific debate continues regarding the potential serious public health impacts from the ever-increasing, continuous exposure to pulsed microwave and millimeter wave signals.

The results of the FDA-sponsored, U.S. National Toxicology Program (NTP) $30 million study on rats and mice exposed to whole-body 2G and 3G cell phone radiofrequency radiation were released on November 1, 2018. The peer-review panel of scientific experts confirmed "clear evidence" of an association between cell phone radiation and heart tumors (malignant schwanomas) in male rats, some evidence of tumors (malignant gliomas) in the brains of male rats and some evidence of tumors in the adrenal glands of male rats.

The above-mentioned NTP study also found "significant increases in DNA damage." Follow-up studies by the NTP to investigate mechanisms of genetic damage associated with cell phone exposure are underway.

These results showing "clear evidence" of cancer from 2G and 3G exposure to laboratory animals call into question the relevance of the FCC's current 23 year old exposure guidelines in protecting the public from 4G, and now 5G technologies.

Two decades ago the FDA stated, "*a significant research effort, involving exposures of large numbers of animals to the various types of cellular phone modulation in current on expected use, coupled with epidemiological surveillance of exposed populations, is needed to provide a further basis for risk assessment of these devices.*" However, the FDA recently rejected their own agency-sponsored study's conclusions, arguing that NTP exposures were not relevant to humans as it was an animal study, despite the fact that the agency had requested the studies and approved the specific design a decade earlier.

In June 2011, IARC had decided to place radiofrequency waves in class "2B", "possibly carcinogenic to humans", on the basis of an increased risk of glioma, a type of malignant brain cancer associated with cell phone use. After publication of numerous studies, including the NTP study, experts considered that RF radiation should be reassessed with high priority. Some scientists are even calling for a reclassification in group 1: "carcinogenic".

On November 7, 2019, the IARC report listed the agents whose carcinogenicity is to be assessed or reassessed during the period 2020-2024. Reassessment of non-ionizing radiation (radiofrequency) will be given high priority (ready for evaluation within 5 years).

Results of PhoneGate Alert actions in France and Europe

As a result of PhoneGate Alert's legal actions in France since April 2018, a total of 18 cell phone models have been withdrawn from the French market or updated for exceeding the SAR threshold.

On October 21, 2019, the French Agency for Food, Environmental and Occupational Health & Safety (ANSES), issued an opinion entitled, "Exposure to mobile telephones carried close to the body", recommending that:

- measures be taken to ensure users are no longer exposed to cell phone radiation levels that exceed regulatory limits
- consumers are educated about the manufacturers' instructions for a separation distance
- compliance testing of emissions be updated so that cell phones' radiation tests are performed in positions of body contact.

The authors of the opinion extend their recommendations to other radiofrequency emitting devices, including toys and tablets.

In response to the ANSES opinion, the French ministries of Health, Ecology and Economy issued a joint press release on October 25, 2019 announcing:

- France will ask the European Commission to strengthen the requirements applicable to new mobile phones placed on the market. The Government will request that the certification tests be carried out in contact with the device (at 0 mm), and not at 5 mm as is currently the case.

- ANFR will develop tools to inform consumers about the emissions of their phone and manufacturers' recommended distance

- The Government will bring together the manufacturers to engage in a voluntary action to update the software of their models so they meet new emission test guidelines.

- The Government also reminds users of its 6 recommended practices to adopt when using a mobile phone to reduce their exposure to radiofrequency radiation including use of a hands-free kit to keep the phone away from the head.

Legal actions in progress against cell phone companies

Within the context of PhoneGate, class actions against cell phone manufacturers have been filed in 2019 in the United States, Canada and France. The first two actions were filed in France against Xiaomi and HMD GLOBAL OY (marketer of Nokia phones) for exceeding the SAR European regulatory limit of 2.0 W/kg. In addition, four new Nokia smartphone models, placed on the market from June 2018, violated the European regulation (directive 2014/53/EU) requiring since June 2016 that the SAR torso be tested at a maximum distance of 5 mm. These four models were measured at 15 mm from the body. The Finnish company also failed to comply with the obligation to provide information on the SAR value and measurement distance in its manuals.

Following publication of the Chicago Tribune's investigation revealing the results of radiation tests on popular mobile phones, a first class action was filed on August 23, 2019 against Apple and

Samsung before the U.S. District Court for the Northern District of California in San Jose, alleging that certain iPhone and Samsung smartphone models exceed the U.S. SAR regulatory limit of 1.6 W/kg.

The plaintiffs also allege that Apple and Samsung market their mobile phones on the assumption that the devices can still be close to their bodies, i.e. in a pocket, and say that older iPhone models had a warning for users to carry their devices at least 10 mm from their bodies. However, more recent models have not provided such advice to consumers. Samsung's marketing material for their devices "implies" that keeping or carrying their phone close to the body is safe.

On September 10, 2019, a new class action against Apple and Samsung was filed by Andrus Anderson LLP in San Francisco, California. Law firms in Illinois and Iowa have joined Andrus in alleging that Apple and Samsung put their clients' health at risk by designing products that emit heightened levels of RF radiation.

On September 5, 2019, a class action against Apple and Samsung was filed in Montreal, Canada, alleging that the radiofrequency radiation of Apple and Samsung phones exceeds the limit legally allowed by the Canadian government.

Congress must take action NOW to protect public health

In this context and in the absence of a response from the FCC, ***we are asking you to support our request for a Congressional hearing to investigate:***

- Industry's deceptive actions with respect to marketing phones that exceed federal safety guidelines.
- Obvious lack of federal regulatory oversight by FCC to ensure that phones are tested as they are being used by today's consumers – in direct contact with the body.
- Setting up major public information and prevention campaigns, particularly targeting young people and pregnant women.

The PhoneGate Alert Association has a scientific advisory committee of researchers and scientists of international renown including Dr. Devra Davis.

Please do not hesitate to contact us and/or the scientific committee for additional information and any questions you may have.

Marc Arazi, M.D.

President, PhoneGate Alert Association
35 rue François Rolland 94130
Nogent-sur-Marne – France

DrArazi@phonegatealert.org

www.phonegatealert.org/en/

Devra Davis, PhD, MPH

President, Environmental Health Trust
P.O Box 58
Teton Village, WY 83025

info@ehtrust.org

www.ehtrust.org

P.S. Please email info@ehtrust.org to request an electronic version of this document that includes hyperlinks of all citations referenced.

RF Exposure Due to Mobile Devices Operated Close to the Human Body

C. Fernández-Rodríguez[#1], G. Bulla[*2], A. A. de Salles[*3]

[#] IFRS, Federal Institute for Education, Science and Technology of Rio Grande do Sul, Canoas, RS, Brazil

[*] Electrical Eng. Dept., UFRGS-Federal University of Rio Grande do Sul, P. Alegre, RS, Brazil

[1]claudio.fernandez@canoas.ifrs.edu.br, {[2]giovani.bulla, [3]asalles}@ufrgs.br

***Abstract* — The SAR (Specific Absorption Rate) simulations due to mobile devices operated in close range to the human head and body are described in this paper. The FDTD (Finite-Difference Time-Domain) numerical method together with realistic children, adolescents and adults' models are employed to estimate the 1 g and the 10 g SAR in different biological tissues. Typical mobile phones, laptops, tablets and virtual reality glasses were considered and the alternatives to reduce the SAR are discussed. The need of new dosimetric parameters and skin and nervous system models for 5G and millimetric waves exposure are also addressed.**

***Keywords* — Radiofrequencies (RF) dosimetry, Specific Absorption Rate (SAR), Mobile Phones, Laptops, Tablets, Virtual Reality glasses.**

I. Introduction

Since in many countries there is a widespread use of wireless transmitting devices by children, adolescents and adults very close to their head and body and sometimes for long time, it is important to assess the RF absorption in different tissues in order to estimate the associated health risks. The available international recommendations limit the SAR (Specific Absorption Rate) in 1.6 W/Kg (in 1 g, FCC [1], IEEE/ANSI [2]) or 2 W/Kg (in 10 g, ICNIRP [3]). They consider only short-term effects (i.e. "thermal" effects) while many peer reviewed scientific papers have demonstrated health risks for long time exposure well below those limits ("non-thermal" effects) [4, 5].

In 2011, IARC classified radiofrequencies (RF) radiation as a "possible human carcinogen" (group 2B) [6]. This includes RF radiation from base stations, mobile phones, laptops, tablets, and other transmitting devices. Due to subsequent epidemiological findings [4, 7 - 9], some independent scientists [4, 5] recommended that these results merit IARC reclassification to 2A ("probably human carcinogen").

Due to the introduction to the 5 G technologies, the use of RF and millimetric waves will increase. Therefore, the revision of the exposure standards and guidelines will be required. Then, the current SAM certification process should be complemented with electromagnetic field (EMF) exposure computer simulations.

In this paper the SAR simulations due to the operation of mobile phones, laptops, tablets and virtual reality (VR) glasses close to the head and the body are summarized.

II. Methodology

The FDTD method (SEMCAD X 14.8 software from SPEAG and CST-Studio from Dassault) together with realistic human models for different ages [10] and a Specific Anthropomorphic Mannequin – SAM [11] are employed.

The dielectric parameters for the adults were obtained from the work of Gabriel [12] which are regularly used for this purpose in medical applications. The age specific parameters for children were estimated based on accepted methods by correlating age specific measurements in pigs [13] with Gabriel data [12] and interpolating as described in [14].

III. Mobile phones

A dual band (900 MHz and 1800 MHz) model was used [15], with a common cell phone case 109 × 60 × 13.9 mm and a Planar Inverted "F" Antenna (PIFA) in the top position.

Fig. 1 shows the psSAR (peak spatial SAR) averaged over cubic volumes containing 1 g and 0.1 g, relative to the psSAR computed over 10 g of continuous tissue for a 900 MHz mobile phone exposure. The head including and excluding pinna, and brain psSAR values for the SAM phantom and the average results for 10 anatomical models are presented [14].

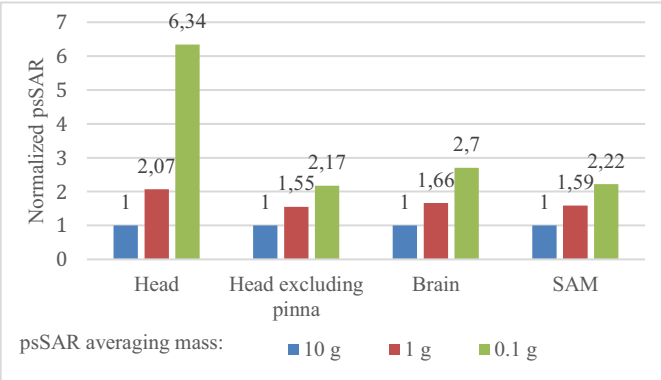

Fig. 1. psSAR averaged over cubic volumes (containing 1 g and 0.1 g) normalized to the psSAR over 10 g of continuous tissue [14].

Consistent with previous reports [16] the averaging volume employed in the modelling is correlated inversely with the calculated maximum tissue dose or psSAR (Fig. 1). Averaging the SAR over 10 g of tissue with a 2 W/kg maximum SAR (consistent with the ICNIRP recommendation) allows over 2-fold greater radiation absorption in the head compared with

averaging over 1 g of tissue with a 1.6 W/kg maximum SAR (consistent with current FCC/FDA methods). Furthermore, averaging SAR over 0.1g – one-tenth the smallest mass in current use – yields a tissue dose up to 6 times that calculated for the commonly used 10 g mass standard.

These differences could be relevant since at the frequencies planned to be used in the 5 G, the EMF is absorbed in the first few millimeters from the surface, then cubes of 1 g or 10 g (with dimensions close to 1 to 3 cm) will be inadequate to assess exposure. Also, more precise models of the skin (e.g. including the helical sweat ducts) should be of interest.

Fig. 2 shows the 1 g psSAR in the skull, brain, hippocampus, cerebellum and eyes at different age models.

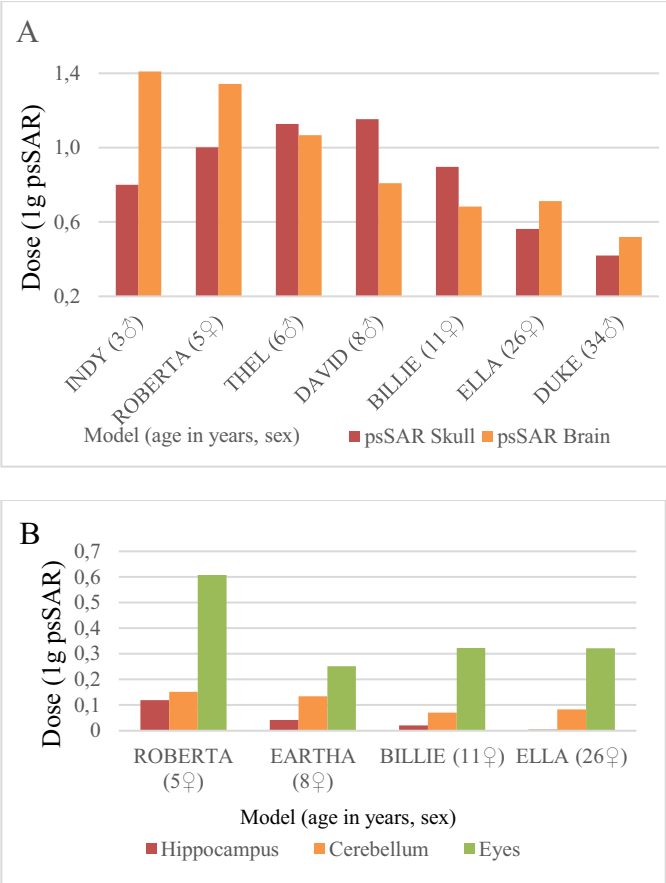

Fig. 2. psSAR in 1g of specific tissues. A. the skull and brain and B. specific tissues in models with these features identified – hippocampus, cerebellum and eyes [14].

As shown in Fig. 2, with the phone against the ear, the psSAR in the hippocampus and the cerebellum is greater in the younger models, with approximately 2-fold greater psSAR in the cerebellum, and even greater psSAR difference in the hippocampus. Also, the eyes are particularly vulnerable to RF radiation, as a result of little fluid circulation and thus poor cooling, plus high RF radiation absorption as a result of relatively high water content. As shown in Fig. 2, the eyes in the youngest models absorb between 2-fold and almost 5-fold higher doses of RF radiation than those of the older models.

Fig.3 shows the trend of psSAR in 1 g of grey matter, as a function of distance from the antenna to the brain.

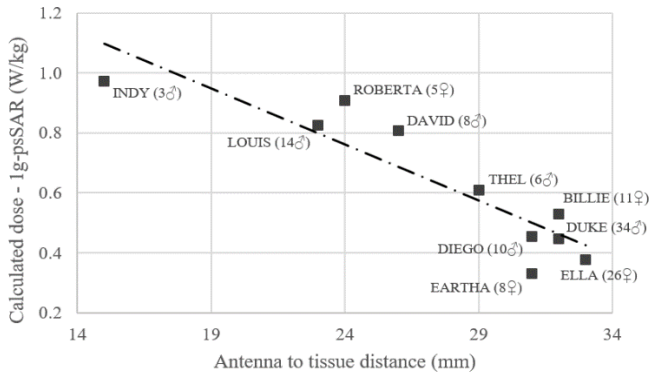

Fig. 3. Trend of psSAR in 1g of grey matter, as a function of distance from the antenna to the brain, for phone in "talk" position [14].

It can be observed that the psSAR in the grey matter as a function of distance from the antenna (i.e. the pinna plus the skull widths), depicts a clear trend of decreasing psSAR with increasing distance (as expected) and illustrates the trend amongst models. Substantial inter-individual variation in psSAR is seen in the more than two-fold difference between the David and Eartha models, both 8 years of age.

Therefore, when measuring the exposure of specific tissues, the distance effect increases the SAR result in smaller models, such as in the children models. This should be considered in the standard revisions.

IV. Laptop Computers

The SAR is estimated in the body of a seated 34-years-old male exposed to 2.4 GHz electromagnetic field (EMF) emitted by laptops. The laptop position is varied vertically from the seated model in order to estimate the changes in SAR associated with changes in distance from the body. A half wave dipole antenna and a planar inverted "F" antenna (PIFA) operating at 2.4 GHz are used in the simulations. The power delivered to the radiating elements was normalized to 100 mW. The antennas were located in the right rear part of the screen and on the right rear part of the keyboard.

Fig. 4 shows the SAR distribution with three distances between laptop and lap (0, 10, 20 cm respectively) for a PIFA.

Fig. 4 - SAR distribution when the PIFA is behind the keyboard: (a) notebook on the lap, (b) notebook at 10 cm from the lap and (c) notebook at 20 cm from the lap.

As is shown in Fig. 4 when the notebook is on the lap, the parts closer to the radiating elements, such as the hands and the laps of the model, absorb higher EMF intensities.

Table 1 - Simulated psSAR values (in W/Kg) with antenna behind keyboard and microcomputer is moved vertically from the lap.

Antenna and distance	psSAR 1g (W/kg)	psSAR 10g (W/kg)
PIFA on the lap	1.40	0.67
PIFA 10 cm from the lap	0.56	0.36
PIFA 20 cm from the lap	1.01	0.55
Dipole on the lap	3.02	1.36
Dipole 10 cm from the lap	0.30	0.20
Dipole 20 cm from the lap	0.31	0.20

The psSAR levels shown in Table I with the dipole are below the limits recommended in [3] for 10 gram cubes, but for 1 gram cubes the psSAR is above the limit recommended in [1]. The psSAR with the PIFA is always below the limits recommended in [1] and [3].

V. TABLETS

An analysis of the interaction of the electromagnetic field generated by a tablet with three different models of human heads: a homogeneous model (SAM) and two heterogeneous models (an adult man, "Duke", 34-years-old and a child, "Thelonious", 6-years-old) was described in [18]. A tablet was simulated at 2.45 GHz assuming 30 mW normalized radiated power. The distance between the eye lens of the head models and the tablet's screen centre was 50 mm, 100 mm, 150 mm and 200 mm. The 10 g and 1g psSAR were estimated and are shown in Table 2.

Table 2 - psSAR over 10g and 1g (mW/kg) [18]

	SAM Phantom		Adult Head (Duke)		Children Head (Thel.)	
	SAR 1g	SAR 10g	SAR 1g	SAR 10g	SAR 1g	SAR 10g
50mm	39.6	26.1	18.9	10.8	35.2	26.4
100mm	11.8	8.1	9.4	4.8	11.3	8.3
150mm	7.5	4.2	7.4	3.3	10.2	4.3
200mm	5.4	2.6	5.2	2.1	7.0	3.0

Fig. 5 shows SAR distribution in the head models, normalized to 0.04 mW/g = 0 dB, with a 30 dB color scale for the SAM Phantom at distances of 50 mm (a); 100 mm (b); 150 mm (c) and 200 mm (d); 34 y-o model "Duke" at distances of 50 mm (e); 100 mm (f); 150 mm (g) and 200 mm (h); 6 y-o model "Thelonious" at distances of 50 mm (i); 100 mm (j); 150 mm (k) and 200 mm (l).

In the simulations for 1g of tissue psSAR the homogeneous SAM phantom head model presented slightly higher levels at distances of 50 mm and 100 mm, on the other hand at

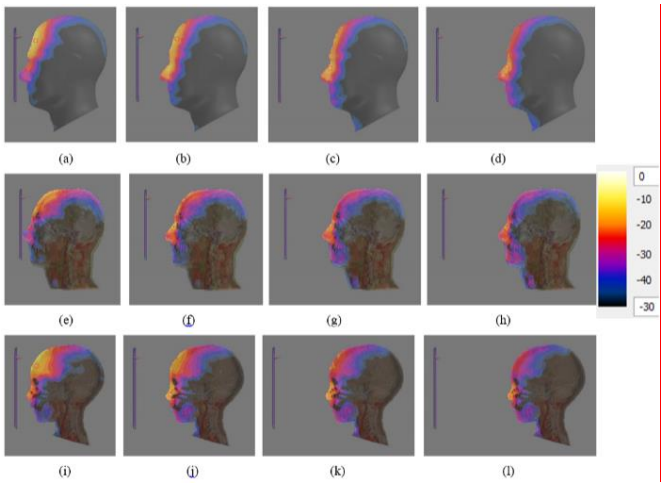

Fig. 5 - SAR distribution in the head models, normalized to 0.04 mW/g = 0 dB, with a 30 dB color scale.

distances of 150 mm and 200 mm the heterogeneous children model presented higher levels. This is a distance effect, since the antennas (red cones in Fig.5) are placed on the top of the tablets. The antenna is located above the anthropomorphic models' head but in front of the SAM forehead (since the SAM is an oversized head) and this has an effect for small distances.

VI. VIRTUAL REALITY

The differences between doses of RF radiation (SAR) in critical components of the brain of the child and adult shown in [14] are clearly illustrated in Fig. 6, in child ("Thelonious") and adult ("Duke") head models, when the phone is used for talking, or for viewing virtual reality.

In Fig. 6 the SAR in cross-sectional views of child and adult male heads, with phone in talk and in virtual reality positions are shown: (A) Axial slices (top view) of "Thelonious" (6-years-old) and "Duke" (34-years-old), with cell phone in cheek position, intersecting the eyes; (B) Axial slices (top view) of "Thelonious" and "Duke", with cell phone in virtual reality position, intersecting the eyes; (C) Quasi-coronal slices (frontal view) of "Thelonious" and "Duke" with cell phone in the cheek position, through the ear; (D) Parasagittal slices (side view) of "Thelonious" and "Duke", with cell phone in virtual reality position, intersecting the eye. The scale is 50 dB with 0 dB=1.6 mW/g.

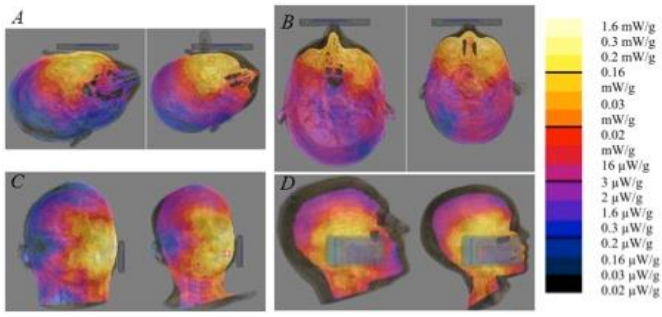

Fig. 6 - SAR in cross-sectional views of child and adult male heads, with phone in talk and in virtual reality positions. The scale is 50 dB with 0 dB=1.6 mW/g [18].

It can be observed that the eyes and frontal lobe of the 6-years-old model experiences a roughly 3-fold higher psSAR than in the adult's eyes and frontal lobe, when a virtual reality glasses containing a phone is placed directly in front of the eyes. This is also mainly due to a distance effect. Deeper absorption penetration is also observed (Fig.6.).

VII. Discussion and Conclusions

The SAR for some typical mobile phones, laptops, tablets and virtual reality glasses were simulated and results were compared to the available recommended exposure guidelines. It was observed that when some of these devices are operated very close to the head or body the simulated results can be above the exposure limits. This is particularly the case for the children models and for particular tissues (e.g. hippocampus and cerebellum). Then the methods to determine regulatory compliance for wireless devices should be re-examined.

Antennas now used in portable devices are monopole, helix, PIFA or other planar structures (generally without ground plane) and they radiate the EMF almost to all directions. Since these devices can be operated close to the head or body, directional antennas radiating the EMF to the direction opposite to the head and body should be developed in order to reduce the SAR in these tissues. This can also contribute to reduce antenna input impedance mismatching when the device is operated close to the body. New antenna techniques including a back plane, electromagnetic band gap (EBG) and artificial magnetic conductor (AMC) could be adequate alternatives aiming to reduce the SAR in the user's head and body. There is also an urgent need for research to evaluate the risks to the eye from use of cell phones in virtual reality applications.

Also, in the near future the use of mm-waves (e.g. 26 GHz and above) will be widespread to carry new services on the 5 G network. Then, the need for new quantities of interest, metrics and exposure limits adequate for these frequencies, as well as modelling new structures, such as the skin and the nervous system, are suggested.

It is very important to remark that the recommendations and the standards usually adopted in different countries only consider the health effects of short time exposure. However, the mobile phones, notebooks, tablets and virtual reality glasses may be used for long time very close to the user's body. Then the long-time health effects must be taken into consideration in order to evaluate the health risks. Meanwhile the Precautionary Principle should be adopted in order to reduce health risks.

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REVIEW
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Risks to Health and Well-Being From Radio-Frequency Radiation Emitted by Cell Phones and Other Wireless Devices

Anthony B. Miller[1], Margaret E. Sears[2], L. Lloyd Morgan[3], Devra L. Davis[3], Lennart Hardell[4], Mark Oremus[5] and Colin L. Soskolne[6,7]*

[1] Dalla Lana School of Public Health, University of Toronto, Toronto, ON, Canada, [2] Ottawa Hospital Research Institute, Prevent Cancer Now, Ottawa, ON, Canada, [3] Environmental Health Trust, Teton Village, WY, United States, [4] The Environment and Cancer Research Foundation, Örebro, Sweden, [5] School of Public Health and Health Systems, University of Waterloo, Waterloo, ON, Canada, [6] School of Public Health, University of Alberta, Edmonton, AB, Canada, [7] Health Research Institute, University of Canberra, Canberra, ACT, Australia

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Edited by:
Dariusz Leszczynski,
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Sareesh Naduvil Narayanan,
Ras al-Khaimah Medical and Health Sciences University,
United Arab Emirates

***Correspondence:**
Anthony B. Miller
ab.miller@utoronto.ca

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Radiation exposure has long been a concern for the public, policy makers, and health researchers. Beginning with radar during World War II, human exposure to radio-frequency radiation[1] (RFR) technologies has grown substantially over time. In 2011, the *International Agency for Research on Cancer* (IARC) reviewed the published literature and categorized RFR as a "possible" (Group 2B) human carcinogen. A broad range of adverse human health effects associated with RFR have been reported since the IARC review. In addition, three large-scale carcinogenicity studies in rodents exposed to levels of RFR that mimic lifetime human exposures have shown significantly increased rates of Schwannomas and malignant gliomas, as well as chromosomal DNA damage. Of particular concern are the effects of RFR exposure on the developing brain in children. Compared with an adult male, a cell phone held against the head of a child exposes deeper brain structures to greater radiation doses per unit volume, and the young, thin skull's bone marrow absorbs a roughly 10-fold higher local dose. Experimental and observational studies also suggest that men who keep cell phones in their trouser pockets have significantly lower sperm counts and significantly impaired sperm motility and morphology, including mitochondrial DNA damage. Based on the accumulated evidence, we recommend that IARC re-evaluate its 2011 classification of the human carcinogenicity of RFR, and that WHO complete a systematic review of multiple other health effects such as sperm damage. In the interim, current knowledge provides justification for governments, public health authorities, and physicians/allied health professionals to warn the population that having a cell phone next to the body is harmful, and to support measures to reduce all exposures to RFR.

Keywords: brain cancer, electromagnetic hypersensitivity, glioma, non-cancer outcomes, policy recommendations, radiofrequency fields, child development, acoustic neuroma

[1] Per IEEE C95.1-1991, the radio-frequency radiation frequency range is from 3 kHz to 300 GHz and is non-ionizing.

INTRODUCTION

We live in a generation that relies heavily on technology. Whether for personal use or work, wireless devices, such as cell phones, are commonly used around the world, and exposure to radio-frequency radiation (RFR) is widespread, including in public spaces (1, 2).

In this review, we address the current scientific evidence on health risks from exposure to RFR, which is in the non-ionizing frequency range. We focus here on human health effects, but also note evidence that RFR can cause physiological and/or morphological effects on bees, plants and trees (3–5).

We recognize a diversity of opinions on the potential adverse effects of RFR exposure from cell or mobile phones and other wireless transmitting devices (WTDs) including cordless phones and Wi-Fi. The paradigmatic approach in cancer epidemiology, which considers the body of epidemiological, toxicological, and mechanistic/cellular evidence when assessing causality, is applied.

CARCINOGENICITY

Since 1998, the *International Commission on Non-Ionizing Radiation Protection* (ICNIRP) has maintained that no evidence of adverse biological effects of RFR exist, other than tissue heating at exposures above prescribed thresholds (6).

In contrast, in 2011, an expert working group of the *International Agency for Research on Cancer* (IARC) categorized RFR emitted by cell phones and other WTDs as a Group 2B ("possible") human carcinogen (7).

Since the IARC categorization, analyses of the large international Interphone study, a series of studies by the Hardell group in Sweden, and the French CERENAT case-control studies, signal increased risks of brain tumors, particularly with ipsilateral use (8). The largest case-control studies on cell phone exposure and glioma and acoustic neuroma demonstrated significantly elevated risks that tended to increase with increasing latency, increasing cumulative duration of use, ipsilateral phone use, and earlier age at first exposure (8).

Pooled analyses by the Hardell group that examined risk of glioma and acoustic neuroma stratified by age at first exposure to cell phones found the highest odds ratios among those first exposed before age 20 years (9–11). For glioma, first use of cell phones before age 20 years resulted in an odds ratio (OR) of 1.8 (95% confidence interval [CI] 1.2–2.8). For ipsilateral use, the OR was 2.3 (CI 1.3-4.2); contralateral use was 1.9 (CI 0.9-3.7). Use of cordless phone before age 20 yielded OR 2.3 (CI 1.4–3.9), ipsilateral OR 3.1 (CI 1.6–6.3) and contralateral use OR 1.5 (CI 0.6–3.8) (9).

Although Karipidis et al. (12) and Nilsson et al. (13) found no evidence of an increased incidence of gliomas in recent years in Australia and Sweden, respectively, Karipidis et al. (12) only reported on brain tumor data for ages 20–59 and Nilsson et al. (13) failed to include data for high grade glioma. In contrast, others have reported evidence that increases in specific types of brain tumors seen in laboratory studies are occurring in Britain and the US:

- The incidence of neuro-epithelial brain cancers has significantly increased in all children, adolescent, and young adult age groupings from birth to 24 years in the United States (14, 15).
- A sustained and statistically significant rise in glioblastoma multiforme across all ages has been described in the UK (16).

The incidence of several brain tumors are increasing at statistically significant rates, according to the 2010–2017 *Central Brain Tumor Registry of the U.S.* (CBTRUS) dataset (17).

- There was a significant increase in incidence of radiographically diagnosed tumors of the pituitary from 2006 to 2012 (APC = 7.3% [95% CI: 4.1%, 10.5%]), with no significant change in incidence from 2012 to 2015 (18).
- Meningioma rates have increased in all age groups from 15 through 85+ years.
- Nerve sheath tumor (Schwannoma) rates have increased in all age groups from age 20 through 84 years.
- Vestibular Schwannoma rates, as a percentage of nerve sheath tumors, have also increased from 58% in 2004 to 95% in 2010-2014.

Epidemiological evidence was subsequently reviewed and incorporated in a meta-analysis by Röösli et al. (19). They concluded that overall, epidemiological evidence does not suggest increased brain or salivary gland tumor risk with mobile phone (MP) use, although the authors admitted that some uncertainty remains regarding long latency periods (>15 years), rare brain tumor subtypes, and MP usage during childhood. Of concern is that these analyses included cohort studies with poor exposure classification (20).

In epidemiological studies, recall bias can play a substantial role in the attenuation of odds ratios toward the null hypothesis. An analysis of data from one large multicenter case-control study of RFR exposure, did not find that recall bias was an issue (21). In another multi-country study it was found that young people can recall phone use moderately well, with recall depending on the amount of phone use and participants' characteristics (22). With less rigorous querying of exposure, prospective cohort studies are unfortunately vulnerable to exposure misclassification and imprecision in identifying risk from rare events, to the point that negative results from such studies are misleading (8, 23).

Another example of disparate results from studies of different design focuses on prognosis for patients with gliomas, depending upon cell phone use. A Swedish study on glioma found lower survival in patients with glioblastoma associated with long term use of wireless phones (24). Ollson et al. (25), however, reported no indication of reduced survival among glioblastoma patients in Denmark, Finland and Sweden with a history of mobile phone use (ever regular use, time since start of regular use, cumulative call time overall or in the last 12 months) relative to no or non-regular use. Notably, Olsson et al. (25) differed from Carlberg and Hardell (24) in that the study did not include use of cordless phones, used shorter latency time and excluded patients older than 69 years. Furthermore, a major shortcoming was that patients with the worst prognosis were excluded, as in Finland

inoperable cases were excluded, all of which would bias the risk estimate toward unity.

In the interim, three large-scale toxicological (animal carcinogenicity) studies support the human evidence, as do modeling, cellular and DNA studies identifying vulnerable subgroups of the population.

The *U.S. National Toxicology Program* (NTP) (National Toxicology Program (26, 27) has reported significantly increased incidence of glioma and malignant Schwannoma (mostly on the nerves on the heart, but also additional organs) in large animal carcinogenicity studies with exposure to levels of RFR that did not significantly heat tissue. Multiple organs (e.g., brain, heart) also had evidence of DNA damage. Although these findings have been dismissed by the ICNIRP (28), one of the key originators of the NTP study has refuted the criticisms (29).

A study by Italy's Ramazzini Institute has evaluated lifespan environmental exposure of rodents to RFR, as generated by 1.8 GHz GSM antennae of cell phone radio base stations. Although the exposures were 60 to 6,000 times lower than those in the NTP study, statistically significant increases in Schwannomas of the heart in male rodents exposed to the highest dose, and Schwann-cell hyperplasia in the heart in male and female rodents were observed (30). A non-statistically significant increase in malignant glial tumors in female rodents also was detected. These findings with far field exposure to RFR are consistent with and reinforce the results of the NTP study on near field exposure. Both reported an increase in the incidence of tumors of the brain and heart in RFR-exposed Sprague-Dawley rats, which are tumors of the same histological type as those observed in some epidemiological studies on cell phone users.

Further, in a 2015 animal carcinogenicity study, tumor promotion by exposure of mice to RFR at levels below exposure limits for humans was demonstrated (31). Co-carcinogenicity of RFR was also demonstrated by Soffritti and Giuliani (32) who examined both power-line frequency magnetic fields as well as 1.8 GHz modulated RFR. They found that exposure to Sinusoidal-50 Hz Magnetic Field (S-50 Hz MF) combined with acute exposure to gamma radiation or to chronic administration of formaldehyde in drinking water induced a significantly increased incidence of malignant tumors in male and female Sprague Dawley rats. In the same report, preliminary results indicate higher incidence of malignant Schwannoma of the heart after exposure to RFR in male rats. Given the ubiquity of many of these co-carcinogens, this provides further evidence to support the recommendation to reduce the public's exposure to RFR to as low as is reasonably achievable.

Finally, a case series highlights potential cancer risk from cell phones carried close to the body. West et al. (33) reported four "extraordinary" multifocal breast cancers that arose directly under the antennae of the cell phones habitually carried within the bra, on the sternal side of the breast (the opposite of the norm). We note that case reports can point to major unrecognized hazards and avenues for further investigation, although they do not usually provide direct causal evidence.

In a study of four groups of men, of which one group did not use mobile phones, it was found that DNA damage indicators in hair follicle cells in the ear canal were higher in the RFR exposure groups than in the control subjects. In addition, DNA damage increased with the daily duration of exposure (34).

Many profess that RFR cannot be carcinogenic as it has insufficient energy to cause direct DNA damage. In a review, Vijayalaxmi and Prihoda (35) found some studies suggested significantly increased damage in cells exposed to RF energy compared to unexposed and/or sham-exposed control cells, others did not. Unfortunately, however, in grading the evidence, these authors failed to consider baseline DNA status or the fact that genotoxicity has been poorly predicted using tissue culture studies (36). As well funding, a strong source of bias in this field of enquiry, was not considered (37).

CHILDREN AND REPRODUCTION

As a result of rapid growth rates and the greater vulnerability of developing nervous systems, the long-term risks to children from RFR exposure from cell phones and other WTDs are expected to be greater than those to adults (38). By analogy with other carcinogens, longer opportunities for exposure due to earlier use of cell phones and other WTDs could be associated with greater cancer risks in later life.

Modeling of energy absorption can be an indicator of potential exposure to RFR. A study modeling the exposure of children 3–14 years of age to RFR has indicated that a cell phone held against the head of a child exposes deeper brain structures to roughly double the radiation doses (including fluctuating electrical and magnetic fields) per unit volume than in adults, and also that the marrow in the young, thin skull absorbs a roughly 10-fold higher local dose than in the skull of an adult male (39). Thus, pediatric populations are among the most vulnerable to RFR exposure.

The increasing use of cell phones in children, which can be regarded as a form of addictive behavior (40), has been shown to be associated with emotional and behavioral disorders. Divan et al. (41) studied 13,000 mothers and children and found that prenatal exposure to cell phones was associated with behavioral problems and hyperactivity in children. A subsequent Danish study of 24,499 children found a 23% increased odds of emotional and behavioral difficulties at age 11 years among children whose mothers reported any cell phone use at age 7 years, compared to children whose mothers reported no use at age 7 years (42). A cross-sectional study of 4,524 US children aged 8–11 years from 20 study sites indicated that shorter screen time and longer sleep periods independently improved child cognition, with maximum benefits achieved with low screen time and age-appropriate sleep times (43). Similarly, a cohort study of Swiss adolescents suggested a potential adverse effect of RFR on cognitive functions that involve brain regions mostly exposed during mobile phone use (44). Sage and Burgio et al. (45) posit that epigenetic drivers and DNA damage underlie adverse effects of wireless devices on childhood development.

RFR exposure occurs in the context of other exposures, both beneficial (e.g., nutrition) and adverse (e.g., toxicants or stress). Two studies identified that RFR potentiated adverse effects of lead on neurodevelopment, with higher maternal use of mobile phones during pregnancy [1,198 mother-child pairs, (46)] and

Attention Deficit Hyper-activity Disorder (ADHD) with higher cell phone use and higher blood lead levels, in 2,422 elementary school children (47).

A study of Mobile Phone Base Station Tower settings adjacent to school buildings has found that high exposure of male students to RFR from these towers was associated with delayed fine and gross motor skills, spatial working memory, and attention in adolescent students, compared with students who were exposed to low RFR (48). A recent prospective cohort study showed a potential adverse effect of RFR brain dose on adolescents' cognitive functions including spatial memory that involve brain regions exposed during cell phone use (44).

In a review, Pall (49) concluded that various non-thermal microwave EMF exposures produce diverse neuropsychiatric effects. Both animal research (50–52) and human studies of brain imaging research (53–56) indicate potential roles of RFR in these outcomes.

Male fertility has been addressed in cross-sectional studies in men. Associations between keeping cell phones in trouser pockets and lower sperm quantity and quality have been reported (57). Both *in vivo* and *in vitro* studies with human sperm confirm adverse effects of RFR on the testicular proteome and other indicators of male reproductive health (57, 58), including infertility (59). Rago et al. (60) found significantly altered sperm DNA fragmentation in subjects who use mobile phones for more than 4 h/day and in particular those who place the device in the trousers pocket. In a cohort study, Zhang et al. (61) found that cell phone use may negatively affect sperm quality in men by decreasing the semen volume, sperm concentration, or sperm count, thus impairing male fertility. Gautam et al. (62) studied the effect of 3G (1.8–2.5 GHz) mobile phone radiation on the reproductive system of male Wistar rats. They found that exposure to mobile phone radiation induces oxidative stress in the rats which may lead to alteration in sperm parameters affecting their fertility.

RELATED OBSERVATIONS, IMPLICATIONS AND STRENGTHS OF CURRENT EVIDENCE

An extensive review of numerous published studies confirms non-thermally induced biological effects or damage (e.g., oxidative stress, damaged DNA, gene and protein expression, breakdown of the blood-brain barrier) from exposure to RFR (63), as well as adverse (chronic) health effects from long-term exposure (64). Biological effects of typical population exposures to RFR are largely attributed to fluctuating electrical and magnetic fields (65–67).

Indeed, an increasing number of people have developed constellations of symptoms attributed to exposure to RFR (e.g., headaches, fatigue, appetite loss, insomnia), a syndrome termed *Microwave Sickness* or *Electro-Hyper-Sensitivity* (EHS) (68–70).

Causal inference is supported by consistency between epidemiological studies of the effects of RFR on induction of human cancer, especially glioma and vestibular Schwannomas, and evidence from animal studies (8). The combined weight of the evidence linking RFR to public health risks includes a broad array of findings: experimental biological evidence of non-thermal effects of RFR; concordance of evidence regarding carcinogenicity of RFR; human evidence of male reproductive damage; human and animal evidence of developmental harms; and limited human and animal evidence of potentiation of effects from chemical toxicants. Thus, diverse, independent evidence of a potentially troubling and escalating problem warrants policy intervention.

CHALLENGES TO RESEARCH, FROM RAPID TECHNOLOGICAL ADVANCES

Advances in RFR-related technologies have been and continue to be rapid. Changes in carrier frequencies and the growing complexity of modulation technologies can quickly render "yesterdays" technologies obsolete. This rapid obsolescence restricts the amount of data on human RFR exposure to particular frequencies, modulations and related health outcomes that can be collected during the lifespan of the technology in question.

Epidemiological studies with adequate statistical power must be based upon large numbers of participants with sufficient latency and intensity of exposure to specific technologies. Therefore, a lack of epidemiological evidence does not necessarily indicate an absence of effect, but rather an inability to study an exposure for the length of time necessary, with an adequate sample size and unexposed comparators, to draw clear conclusions. For example, no case-control study has been published on fourth generation (4G; 2–8 GHz) Long-term Evolution (LTE) modulation, even though the modulation was introduced in 2010 and achieved a 39% market share worldwide by 2018 (71).

With this absence of human evidence, governments must require large-scale animal studies (or other appropriate studies of indicators of carcinogenicity and other adverse health effects) to determine whether the newest modulation technologies incur risks, prior to release into the marketplace. Governments should also investigate short-term impacts such as insomnia, memory, reaction time, hearing and vision, especially those that can occur in children and adolescents, whose use of wireless devices has grown exponentially within the past few years.

The Telecom industry's fifth generation (5G) wireless service will require the placement of many times more small antennae/cell towers close to all recipients of the service, because solid structures, rain and foliage block the associated millimeter wave RFR (72). Frequency bands for 5G are separated into two different frequency ranges. Frequency Range 1 (FR1) includes sub-6 GHz frequency bands, some of which are bands traditionally used by previous standards, but has been extended to cover potential new spectrum offerings from 410 to 7,125 MHz. Frequency Range 2 (FR2) includes higher frequency bands from 24.25 to 52.6 GHz. Bands in FR2 are largely of millimeter wave length, these have a shorter range but a higher available bandwidth than bands in the FR1. 5G technology is being developed as it is also being deployed, with large arrays

of directional, steerable, beam-forming antennae, operating at higher power than previous technologies. 5G is not stand-alone—it will operate and interface with other (including 3G and 4G) frequencies and modulations to enable diverse devices under continual development for the "internet of things," driverless vehicles and more (72).

Novel 5G technology is being rolled out in several densely populated cities, although potential chronic health or environmental impacts have not been evaluated and are not being followed. Higher frequency (shorter wavelength) radiation associated with 5G does not penetrate the body as deeply as frequencies from older technologies although its effects may be systemic (73, 74). The range and magnitude of potential impacts of 5G technologies are under-researched, although important biological outcomes have been reported with millimeter wavelength exposure. These include oxidative stress and altered gene expression, effects on skin and systemic effects such as on immune function (74). *In vivo* studies reporting resonance with human sweat ducts (73), acceleration of bacterial and viral replication, and other endpoints indicate the potential for novel as well as more commonly recognized biological impacts from this range of frequencies, and highlight the need for research before population-wide continuous exposures.

GAPS IN APPLYING CURRENT EVIDENCE

Current exposure limits are based on an assumption that the only adverse health effect from RFR is heating from short-term (acute), time-averaged exposures (75). Unfortunately, in some countries, notably the US, scientific evidence of the potential hazards of RFR has been largely dismissed (76). Findings of carcinogenicity, infertility and cell damage occurring at daily exposure levels—within current limits—indicate that existing exposure standards are not sufficiently protective of public health. Evidence of carcinogenicity alone, such as that from the NTP study, should be sufficient to recognize that current exposure limits are inadequate.

Public health authorities in many jurisdictions have not yet incorporated the latest science from the U.S. NTP or other groups. Many cite 28-year old guidelines by the *Institute of Electrical and Electronic Engineers* which claimed that "Research on the effects of chronic exposure and speculations on the biological significance of non-thermal interactions have not yet resulted in any meaningful basis for alteration of the standard" (77)[2].

Conversely, some authorities have taken specific actions to reduce exposure to their citizens (78), including testing and recalling phones that exceed current exposure limits.

While we do not know how risks to individuals from using cell phones may be offset by the benefits to public health of being able to summon timely health, fire and police emergency services, the findings reported above underscore the importance of evaluating potential adverse health effects from RFR exposure, and taking pragmatic, practical actions to minimize exposure.

We propose the following considerations to address gaps in the current body of evidence:

- As many claim that we should by now be seeing an increase in the incidence of brain tumors if RFR causes them, ignoring the increases in brain tumors summarized above, a detailed evaluation of age-specific, location-specific trends in the incidence of gliomas in many countries is warranted.
- Studies should be designed to yield the strongest evidence, most efficiently:
  - ➢ Population-based case-control designs can be more statistically powerful to determine relationships with rare outcomes such as glioma, than cohort studies. Such studies should explore the relationship between energy absorption (SAR[3]), duration of exposure, and adverse outcomes, especially brain cancer, cardiomyopathies and abnormal cardiac rythms, hematologic malignancies, thyroid cancer.
  - ➢ Cohort studies are inefficient in the study of rare outcomes with long latencies, such as glioma, because of cost-considerations relating to the follow-up required of very large cohorts needed for the study of rare outcomes. In addition, without continual resource-consuming follow-up at frequent intervals, it is not possible to ascertain ongoing information about changing technologies, uses (e.g., phoning vs. texting or accessing the Internet) and/or exposures.
  - ➢ Cross-sectional studies comparing high-, medium-, and low-exposure persons may yield hypothesis-generating information about a range of outcomes relating to memory, vision, hearing, reaction-time, pain, fertility, and sleep patterns.
- Exposure assessment is poor in this field, with very little fine-grained detail as to frequencies and modulations, doses and dose rates, and peak exposures, particularly over the long-term. Solutions such as wearable meters and phone apps have not yet been incorporated in large-scale research.
- Systematic reviews on the topic could use existing databases of research reports, such as the one created by *Oceania Radiofrequency Science Advisory Association* (79) or EMF Portal (80), to facilitate literature searches.
- Studies should be conducted to determine appropriate locations for installation of antennae and other broadcasting systems; these studies should include examination of biomarkers of inflammation, genotoxicity, and other health indicators in persons who live at different radiuses around these installations. This is difficult to study in the general population because many people's greatest exposure arises from their personal devices.
- Further work should be undertaken to determine the distance that wireless technology antennae should be kept away from humans to ensure acceptable levels of safety, distinguishing among a broad range of sources (e.g., from commercial transmitters to Bluetooth devices), recognizing that exposures fall with the inverse of the square of the distance

[2]The FCC adopted the IEEE C95.1 1991 standard in 1996.

[3]When necessary, SAR values should be adjusted for age of child in W/kg.

(The inverse-square law specifies that intensity is inversely proportional to the square of the distance from the source of radiation). The effective radiated power from cell towers needs to be regularly measured and monitored.

POLICY RECOMMENDATIONS BASED ON THE EVIDENCE TO DATE

At the time of writing, a total of 32 countries or governmental bodies within these countries[4] have issued policies and health recommendations concerning exposure to RFR (78). Three U.S. states have issued advisories to limit exposure to RFR (81–83) and the *Worcester Massachusetts Public Schools* (84) voted to post precautionary guidelines on Wi-Fi radiation on its website. In France, Wi-Fi has been removed from pre-schools and ordered to be shut off in elementary schools when not in use, and children aged 16 years or under are banned from bringing cell phones to school (85). Because the national test agency found 9 out of 10 phones exceeded permissible radiation limits, France is also recalling several million phones.

We therefore recommend the following:

1. Governmental and institutional support of data collection and analysis to monitor potential links between RFR associated with wireless technology and cancers, sperm, the heart, the nervous system, sleep, vision and hearing, and effects on children.
2. Further dissemination of information regarding potential health risk information that is in wireless devices and manuals is necessary to respect users' *Right To Know*. Cautionary statements and protective measures should be posted on packaging and at points of sale. Governments should follow the practice of France, Israel and Belgium and mandate labeling, as for tobacco and alcohol.
3. Regulations should require that any WTD that could be used or carried directly against the skin (e.g., a cell phone) or in close proximity (e.g., a device being used on the lap of a small child) be tested appropriately as used, and that this information be prominently displayed at point of sale, on packaging, and both on the exterior and within the device.
4. IARC should convene a new working group to update the categorization of RFR, including current scientific findings that highlight, in particular, risks to youngsters of subsequent cancers. We note that an IARC Advisory Group has recently recommended that RFR should be re-evaluated by the IARC Monographs program with high priority.
5. The World Health Organization (WHO) should complete its long-standing RFR systematic review project, using strong modern scientific methods. National and regional public health authorities similarly need to update their understanding and to provide adequate precautionary guidance for the public to minimize potential health risks.
6. Emerging human evidence is confirming animal evidence of developmental problems with RFR exposure during pregnancy. RFR sources should be avoided and distanced from expectant mothers, as recommended by physicians and scientists (babysafeproject.org).
7. Other countries should follow France, limiting RFR exposure in children under 16 years of age.
8. Cell towers should be distanced from homes, daycare centers, schools, and places frequented by pregnant women, men who wish to father healthy children, and the young.

Specific examples of how the health policy recommendations above, invoking the Precautionary Principle, might be practically applied to protect public health, are provided in the **Annex**.

[4]Argentina, Australia, Austria, Belgium, Canada, Chile, Cyprus, Denmark, European Environmental Agency, European Parliament, Finland, France, French Polynesia, Germany, Greece, Italy, India, Ireland, Israel, Namibia, New Zealand, Poland, Romania, Russia, Singapore, Spain, Switzerland, Taiwan, Tanzania, Turkey, United Kingdom, United States.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Conflict of Interest Statement: The authors declare that this manuscript was drafted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest, although subsequent to its preparation, DD became a consultant to legal counsel representing persons with glioma attributed to radiation from cell phones.

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ANNEX: EXAMPLES OF ACTIONS FOR REDUCING RFR EXPOSURE

1. Focus actions for reducing exposure to RFR on pregnant women, infants, children and adolescents, as well as males who might wish to become fathers.
2. Reduce, as much as possible, the extent to which infants and young children are exposed to RFR from Wi-Fi-enabled devices such as baby monitors, wearable devices, cell phones, tablets, etc.
3. Avoid placing cell towers and small cell antennae close to schools and homes pending further research and revision of the existing exposure limits. In schools, homes and the workplace, cable or optical fiber connections to the Internet are preferred. Wi-Fi routers in schools and daycares/kindergartens should be strongly discouraged and programs instituted to provide Internet access via cable or fiber.
4. Ensure that WTDs minimize radiation by transmitting only when necessary, and as infrequently as is feasible. Examples include transmitting only in response to a signal (e.g., accessing a router or querying a device, a cordless phone handset being turned on, or voice or motion activation). Prominent, visible power switches are needed to ensure that WTDs can be easily turned on only when needed, and off when not required (e.g., Wi-Fi when sleeping).
5. Lower permitted power densities in close proximity to fixed-site antennae, from "occupational" limits to exposure limits for the general public.
6. Update current exposure limits to be protective against the non-thermal effects of RFR. Such action should be taken by all heath ministries and public health agencies, as well as industry regulatory bodies. Exposure limits should be based on measurements of RFR levels related to biological effects (2).
7. Ensure that advisories relating to cell phone use are placed in such a way that purchasers can find them easily, similar to the Berkeley Cell Phone "Right to Know" Ordinance (86).
8. Advise the public that texting and speaker mode are preferable to holding cell phones to the ear. Alternatively, use hands-free accessories for cell phones, including air tube headsets that interrupt the transmission of RFR.
9. When possible, keep cell phones away from the body (e.g., on a nearby desk, in a purse or bag, or on a mounted hands-free accessory in motor vehicles).
10. Delay the widespread implementation of 5G (and any other new technology) until studies can be conducted to assess safety. This includes a wide range of household and community-wide infrastructure WTDs and self-driving vehicles, as well as the building of 5G minicells.
11. Fiber-optic connections for the Internet should be made available to every home, office, school, warehouse and factory, when and where possible.

GLOSSARY

ALARA	As Low a level As Reasonably Achievable
CBTRUS	Central Brain Tumor Registry of the United States
CI	Confidence Interval
EMR	Electro Magnetic Radiation
IARC	International Agency for Research on Cancer
ICNIRP	International Commission on Non-Ionizing Radiation Protection
INEP	International Network for Epidemiology in Policy
LTE	Long-Term Evolution modulation
NTP	U.S. National Toxicology Program
OR	Odds Ratio
RFR	Radio-Frequency Radiation
SAR	Specific Absorption Rate
WTD	Wireless Transmitting Device