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2016 Review:

Radiofrequency and Health

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Introduction

The World Health Organisation (WHO) and the International Agency for Research on Cancer (IARC) in 2011 classified exposure to radiofrequency (RF) fields as being ”possibly carcinogenic”, a designation which is applied to “agents, mixtures and exposure circumstances for which there is limited evidence of carcinogenicity in humans and less than sufficient evidence of carcinogenicity in experimental animals”.[1] This “possibly carcinogenic” classification was based on studies showing that persons diagnosed with glioma, a type of brain tumour, were more likely to have reported frequent and long-term wireless (cell) phone use than a healthy control group.[2] Classifying RF as “possibly carcinogenic” added to concerns that have been expressed by citizens and by scientists about specific sources of exposure to RF and about a variety of health effects ascribed to RF. These concerns have been supported by the Canadian House of Commons Standing Committee on Health, which recommended more scientific research directed towards a better understanding of the risks of cancer and other health effects associated with RF, as well as increasing industry and public awareness of the need to reduce exposures.

In this document, we describe the physics of RF; national and international exposure limits; exposures from common RF-emitting devices, including cell phones, Wi-Fi computer networks, smart meters, and baby monitors; how cells and tissues may be affected by exposures to RF; and potential health effects, such as cancer, reproductive and developmental effects, and symptomatic complaints, including electrohypersensitivity (EHS). Finally, although there is limited scientific evidence of harm, suggestions are given as to how to reduce personal exposures to RF.

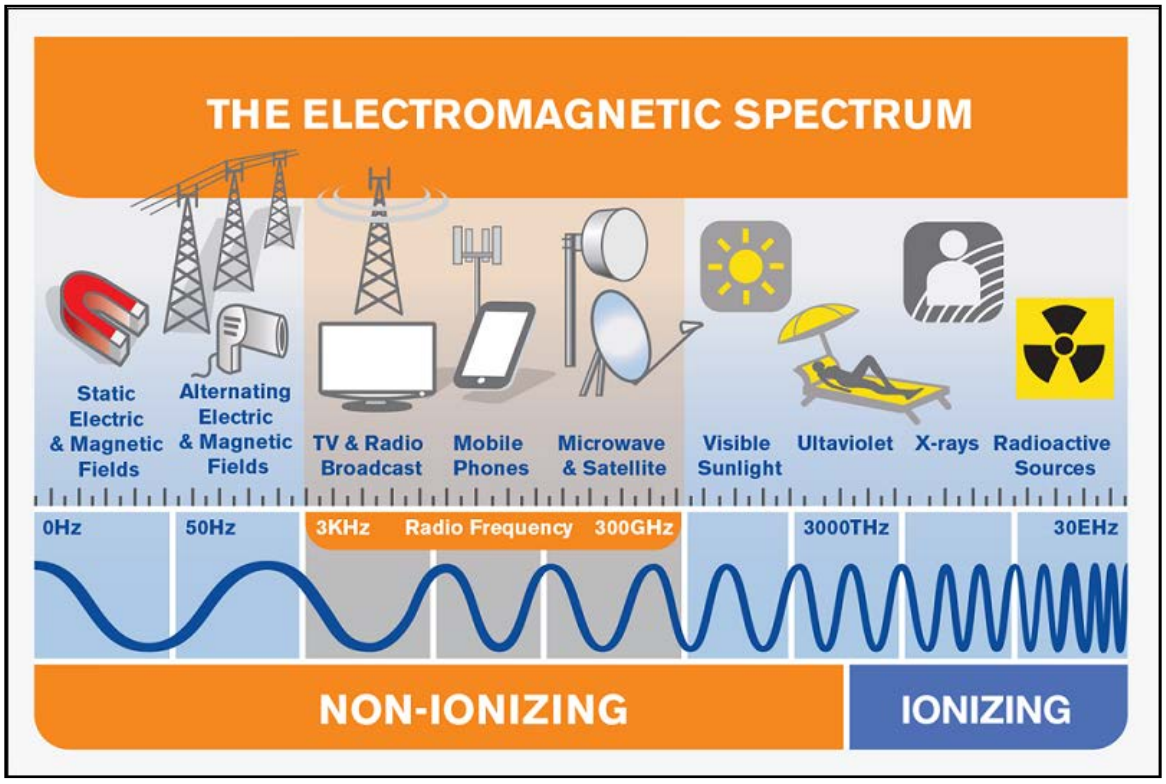
The 2013 BC Centre for Disease Control Radiofrequency Toolkit[3] (368 pages in length) and its references served as the primary source of information on exposure and potential health effects from RF. Searches of the more recent scientific literature were also conducted using Medline and Google Scholar databases. Several scientific review panels have published reports in the past few years that cover much of this material in more detail. These reports include:

- Royal Society of Canada Expert Panel. A review of Safety Code 6 (2013): Health Canada’s safety limits for exposure to radiofrequency fields. Health Canada, 2014[4]
- Independent Advisory Group on Non-ionizing Radiation. Health effects from radiofrequency electromagnetic fields. Health Protection Agency, United Kingdom, 2012[5]
- Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). Potential health effects of exposure to electromagnetic fields (EMF). European Commission, 2015[6]
- Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). Review of radiofrequency health effects research – scientific literature 2000-2012. Report by the ARPANSA Radiofrequency Expert Panel 2014[7]

What is radiofrequency (RF) radiation?

The electromagnetic (EM) spectrum (Figure1) has characteristics of both propagated waves (ripples or oscillations on a pond are an example of a propagated wave) and of particles. Based on wavelength and energy carried, the EM spectrum can be divided into ionizing and non-ionizing regions: EM waves which fall within the “ionizing radiation" region have enough energy to remove tightly bound electrons from

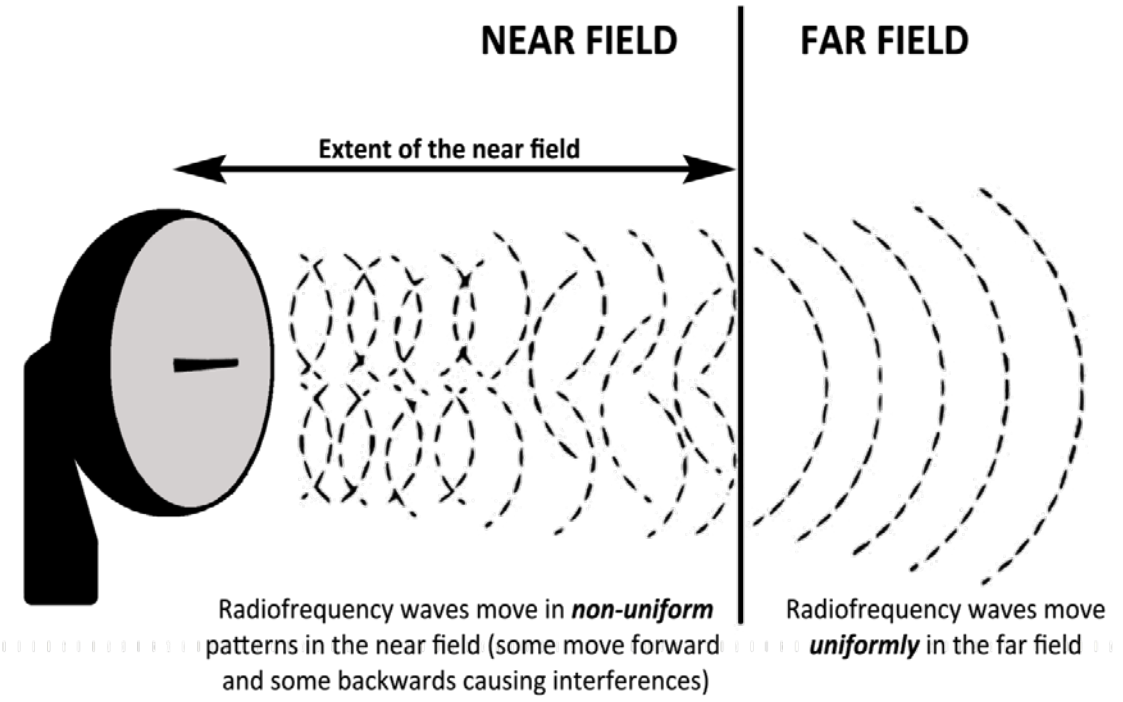
atoms, thus creating charged particles, or ions. This is the type of EM energy that people usually think of as 'radiation'. Examples of "ionizing radiation" are x-rays and gamma rays. Energy transferred by ionizing radiation is used in nuclear power plants to generate energy, and medically to kill cancer cells and for diagnostic imaging. The region of the EM spectrum that has enough energy to displace atoms in a molecule or cause them to vibrate, but not enough energy to remove electrons, is referred to as "non-ionizing radiation." Examples of this kind of radiation are visible light and radiofrequency (RF) waves including microwaves. RF waves have frequencies between 3 KHz (3000 Hz) and 300 GHz (300 billion Hz, one hertz being equal to one oscillation [or complete wave] per second).



Source: International Telecommunication Union[8]

Figure 1 – Electromagnetic Spectrum

RF radiation is generated naturally during lightning and through discharges of the sun, stars and other astronomical bodies. Nowadays, man-made RF sources such as radio, television, cell phones, cordless (DECT) phones, home monitors, and wireless internet routers are widespread and contribute to RF exposure depending on the technology, how it is used, and distance from the sources. RF-based technologies are used in homes, workplaces, schools, public spaces, and in public transportation (e.g., buses, mass transit, cars, trains, ferries, cruise ships, and most recently airplanes).



Source (adapted): "Far and Near Fields" courtesy of Goran M. Djuknic, Wikimedia[9]

Figure 2 – RF wave patterns in the near field and far field

RF waves travelling in air spread out from the "near field", an area of higher exposure closest to the RF source, to the "far field" (Figure 2). The wavelength and size of the RF antenna determine the area of the near field and the distance it extends from the source. For small antennas such as those of cell phones, Wi-Fi routers, laptops, tablets, Bluetooth, and other RF consumer devices, the length of the near-field ranges from a few centimeters (cm) to approximately 20 cm. For example, a mobile phone held close to one's ear exposes the head and the tissues inside it to near-field radiation. For large RF emitters, such as the dish-shaped antennas used for broadcasting and telecommunication, the near field can extend many meters from the source: a 300-MHz broadcasting dish of 2 meters in diameter generates a near field of approximately 8 meters. This would be a worker safety concern rather than a public health issue since the public is barred access to broadcast antennas. Due to the complex, non-uniform nature of wave patterns in the near field (Figure 2), it is difficult to directly measure exposure close to an RF source. Rather, exposure is expressed in terms of Specific Absorption Rate (SAR), a measure of energy transfer from a source to a body or body part, expressed as Watts/kilogram (W/kg).

In the far field, where RF waves move uniformly, energy transfer decreases rapidly with increasing distance from the antenna. Exposure is generally expressed in terms of power density (W/cm^2), which is the rate of RF energy impacting on a surface area such as the skin. RF exposure in the far field can be estimated accurately if the characteristics of the antenna and the distance from the source are known.

Do exposure limits protect us from RF waves in the environment?

Health Canada's Safety Code 6: "*Limits of Human Exposure to Radiofrequency Electromagnetic Energy in the Frequency Range from 3 kHz to 300 GHz"*, revised in 2015,[10] establishes maximum output levels for devices emitting RF radiation. For industrial exposures to high-intensity RF fields in the frequency range 3 kHz – 10 MHz (such as induction heating used in the aviation and automotive industries, in pipe fitting, shipbuilding, and foundries), safety limits are primarily based on avoiding stimulation of peripheral nerves and muscles as well as electric shocks and skin burns. For the general public, who are typically exposed to lower intensity RF at frequencies greater than 10 MHz, Safety Code 6 exposure limits are set to avoid tissue heating from exposure to RF. The exposure levels have been set at an intensity level below which no observed adverse effects occur from exposures even if encountered daily over a lifetime. These exposure limits include a margin of safety (1/50 of the observed no adverse effect level) designed to enhance protection against thermal effects.

The exposure limits take into account total (aggregate) exposure from all sources of RF energy. While exposure to multiple RF fields can result in an increase or decrease of field strength depending on wave movement patterns, a conservative approach taken by regulators is that the aggregate exposure incurred by a person is the sum of exposures from each device considered alone. Safety Code 6 limits are in line with the recommendations of the International Commission on Non-Ionizing Radiation Protection (ICNIRP),[11] which have been adopted by the UK, Europe, and most other countries outside of Canada and the US. International studies often reference measurements of RF as a percentage of the ICNIRP limits.

How much exposure is generated from individual RF-emitting devices?

Cell phones

The peak power output of older cell phones (1st and 2nd generation) was as high as 2 W. For current cell phone models transmission is continuous at lower maximal power outputs of up to 250 mW (1/4 of a watt). For near-field exposures from devices, such as cell phones, held close to the body, power density measures do not apply and instead, SAR is calculated. The SAR due to cell phone exposure is generally in the order of 1 W/kg, but can be slightly lower or higher depending on the cell phone model. When the cell phone is in use, its distance from the head is an important factor to consider. The absorbed power for a cell phone placed 10 cm from the head is more than 10 times lower than when it is held close to the ear, and about 100 times lower than when held 40 cm from the head, such as when texting.[12] SAR can also increase if cell phones are used in enclosed areas such as offices due to signal dampening, thus requiring higher cell phone power output to reach the nearest router, or near metallic walls such as inside elevators, where waves reflecting off the walls can increase exposure. In general, as technology has improved, the RF energy emitted from individual cell phones has decreased. As the cell phone network is enlarged with more antennas installed, cell phones require less power to connect to the network, thereby lowering the user's exposure to RF waves.

Cordless (DECT) phones

Cordless phones are low-power wireless handsets that communicate within the short range of a single, private base station connected to a fixed telephone line. Digital Enhanced Cordless Telecommunications (DECT) phones utilize the 1880-1900 MHz band and produce pulsed waves in the form of very short bursts produced at brief intervals. Unlike mobile phones, DECT phones do not possess adaptive power control; therefore, the distance between handset and the base station has no influence on the device power output. While emissions from the handset only occur during a call, those from the base station are normally continuous. When no calls are in progress, the base station transmits a brief pulse every 10 milliseconds; however, in certain models, the base station never emits if the handset is in place. The peak transmitting power of the base station and handset is up to 250 mW. Averaged over time, however, emissions are lower, since transmission is not continuous. As cited by the Swiss Federal Office of Public Health, measured SAR values obtained on tissue-simulating head phantoms were between 0.01 and 0.05 W/kg, much lower than Health Canada's basic restriction of 1.6 W/kg for the protection of the general population. [13]

Cell phone base stations

Cell phone networks include several base stations, each one equipped with one or several RF antennas installed at different locations to ensure full coverage to users. Large RF antennas having a broadcast range of up to 10 kilometers are generally mounted on masts or rooftops as high as 50 meters above ground level in order to avoid signal obstruction by tall buildings, dense foliage, and hilly landscapes. These antennas use relatively high powers (as much as 60 W) and operate at frequencies ranging from 800 MHz to 2100 MHz. Some recent cell phone technologies (4th generation) use frequencies as high as 3800 MHz. While cell phone coverage is mainly achieved using large RF antennas, additional coverage within dense neighbourhoods is provided by low-power antennas (of a few watts) mounted on building walls or lamp posts. These small antennas only add coverage to immediate areas because of their shorter range, rarely exceeding a few hundred meters.

In British Columbia, a series of power density measurements were conducted in 2004 by a BCCDC team at 20 different sites across the province using a dedicated RF survey unit mounted on a vehicle. The power density readings collected in the survey showed that the base stations were largely compliant with Safety Code 6 (SC6) guidelines with exposures 3000 to 1,000,000 times lower than SC6 limits for uncontrolled (public non-workplace) environments. Detailed results of the surveys for all visited BC locations are available online.[14] In the UK, a survey around cell phone base stations was carried out between 1998 and 2000 at 118 locations.[15] The measured power densities ranged from 0.01 mW/m^2 to 1 mW/m^2, equivalent to 0.0002% to 0.02% of ICNIRP public limits. Additional large-scale RF surveys, recently carried out near base station sites in China[16] and Europe,[17] reached similar conclusions with exposure levels thousands of times below regulatory limits.

Wi-Fi computer networks

Wi-Fi computer networks are RF-based communication systems incorporating one or more routers and several Wi-Fi-enabled computer systems. A router is a wired piece of hardware directly connected to the internet that serves as a base station for wireless-enabled computers and peripherals (printers,

scanners, etc.). Wi-Fi systems are categorized as low-power devices; they seldom exceed 100 mW in power[18] and operate at "duty cycles" of 10% or less.[19,20] The duty cycle is the fraction of time during which the device is transmitting radiofrequency waves. In comparison, cell phones use greater powers (up to 2 W) and their duty cycles are generally higher due to extensive use.

An extensive investigation in the UK[21] measuring Wi-Fi exposure at different distances from a large wireless network of 12 routers and 15 laptops operating simultaneously found exposures to be a small fraction of regulatory reference levels.[22] A study by Industry Canada[23] measured exposure from a Wi-Fi network inside a boardroom equipped with 2 routers and 24 laptops (continuously uploading or downloading large files). The highest exposure measured inside the room reached approximately 0.19% of Safety Code 6 limits. In general, exposures from Wi-Fi emissions are much lower in comparison to cell phones because of the low power of routers (less than 0.1 W) and laptops (less than 0.030 W) and the greater distance of people from those RF sources. For example, SAR to the head of a child using a laptop connected to Wi-Fi has been estimated as 0.0057 W/kg (from both the router and laptop), which represents less than 1% of the typical SAR values for cell phone use.[24]

Smart Meters

Smart meters are wireless devices used by utility companies to remotely collect data on the consumption of electricity, water, and gas. Utility readings taken by smart meters are communicated to wireless data collectors, which in turn relay the information to utility company servers. Smart meters come in a variety of shapes and designs, depending on their manufacturer, but they generally operate at a frequency of 900 MHz and a power of 1 W or less. These characteristics place smart meters at about the same level of emissions as second generation cell phones. However, smart meters only emit for short periods of time during the day, ranging from 1−6 minutes in 24 h ("duty cycles" of 0.07% to 0.4%).[25]

In BC, emissions from a bank of 10 BC Hydro's Itron smart meters were measured by BCCDC at varying distances using a broadband RF survey meter.[26] The maximum time-averaged exposure recorded at a distance of 30 cm was approximately 0.0028 $\mu W/cm^2$, which is equivalent to 0.001% of SC6 limits at 900 MHz. In the United States, extensive exposure measurements were carried out using frequency-selective survey meters and the maximum exposure levels obtained were found to be less than 1% of the FCC limits.[27,28] EMC Technologies in Australia tested 1-W smart meters operating at a maximum duty cycle of 2.5% (*i.e.*, 36 min per day), outside and inside homes in 16 different dwellings. At 30 cm from the source, the maximum exposure outside homes with the meters boxes left open reached a power density of 3.8 μ/cm^2 (0.8% of Australian limits), while the maximum exposure inside homes amounted to 0.002562 μ/cm^2 (0.0056% of Australian limits). With the meter boxes closed, the maximum power density recorded outside homes dropped to 0.5 $\mu W/cm^2$ (0.01% of Australian limits).[29] The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) took measurements at a distance of 50 cm from 1-W smart meters. Using a duty cycle of 0.7%, as measured by the investigators, the time-averaged exposures were 0.005 $\mu W/cm^2$ and 0.002 $\mu W/cm^2$, corresponding to 0.001% and 0.0004% of ICNIRP reference levels, respectively.[30]

Thus, RF is emitted at low power and only intermittently by smart meters, with measured exposure levels well below regulatory limits, decreasing rapidly with distance from the device.

Baby monitors

Baby monitors are RF-emitting devices used in households and nurseries to provide remote monitoring of sounds made by infants. The RF-emitting device is placed at a distance of 30 cm to 1 m from the baby's bed and the RF receiver is positioned in another room. Baby monitors come in different designs and can operate at several frequencies from 12 MHz to 2.4 GHZ and at RF powers up to 3 W. There are relatively few investigations of RF exposure levels associated with baby monitors. A study in Australia conducted by EMC technologies[29] measured time-averaged power densities from baby monitors of up to 14.8 µW/cm^2 at 30 cm, 5.3 µW/cm^2 at 50 cm, and 1.3 µW/cm^2 at 1 m, corresponding to 3.29%, 1.1%, and 0.3% of ICNIRP reference levels, respectively.[31] Thus, distance of the RF-emitting device of the baby monitor from the infant is an important determinant of exposure.

Comparison of exposures from common RF-emitting devices

Cell phones, base stations, wireless computer networks (Wi-Fi), smart meters, and baby monitors emit radiofrequency waves at different levels, but all are compliant with the current regulatory guidelines. A comparison of common RF-emitting devices, most taken at a distance of 30 cm from the source, shows that baby monitors convey relatively higher exposures at 3.3% of ICNIRP exposure limits, as presented in Figure 3 below. As indicated in the notes below the figure, the exposure from a smart meter measured outside of the home is much higher than that measured inside, due to RF wave attenuation from the metal backing and wall. In comparison to the exposure to a bystander from a cell phone operating 30 cm away (2% of the exposure limits), depending upon the model and generation of the cell phone used, exposure from a cell phone held at the head could reach 10% to 70% of regulatory limits.[5]

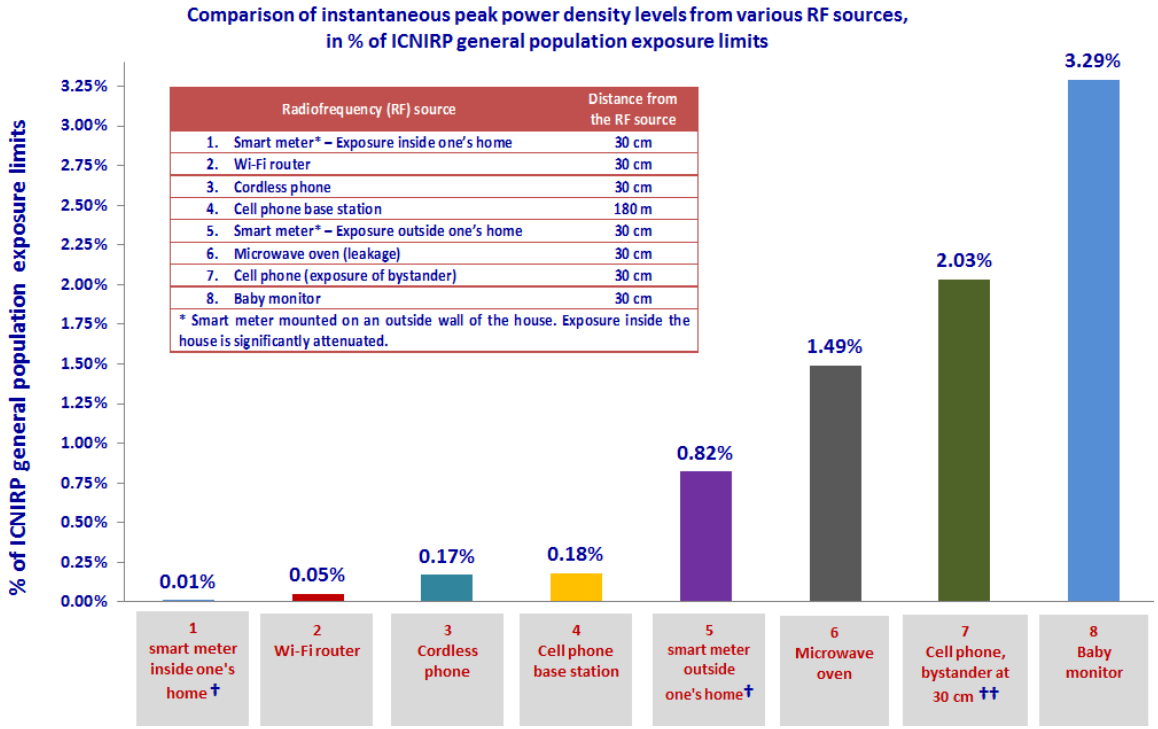


Figure 3 – Comparison of peak power densities from various radiofrequency sources
(data from EMC Technologies-Australia[29], except for cell phone base stations from NRPB-UK15)

† The tested smart meter was mounted on an external wall of the house. The exposure outside the house (0.82% ICNIRP) was measured directly in front of the smart meter, while exposure inside the house (0.01% ICNIRP) was measured on the opposite side of the wall behind the smart meter. Exposure inside the house was 82 times lower than that outside due to significant wave attenuation by the wall and the smart meter's metallic backing.

†† The cell phone exposure level of Figure 3 (2.03% ICNIRP) is to the whole body of a bystander standing at a distance of 30 cm from a cell phone in use. However, the exposure to a cell phone user's head with the cell phone positioned at the ear (data not included in the graph) is greater and could reach 10 to 70% of ICNIRP limits at maximum cell phone output.[5]

In reality, we are exposed to multiple RF-emitting devices at any one time. Recent studies in Europe measured total RF exposure to residents from multiple sources of RF and showed that none of the exposure levels exceeded European guidelines (comparable to Canada's Safety Code 6).[17] In a separate study, the highest total personal RF exposures in Belgium and Switzerland were found in public transportation, (trains, buses, trams, and metro lines) in comparison to outdoor areas (residential areas, downtown, and suburbs) and indoor spaces (airport, railway stations, and shopping centres).[32]

Can exposure to RF waves affect cells and tissues?

Almost all research on the potential biological and health effects of RF has focused on cell phones, as they emit more RF radiation than other common public RF communication devices and when held to the ear, RF energy from a cell phone is absorbed by the head.

Given that RF does not directly cause ionization and damage to cells and tissues, how can it affect people? Two classes of biological mechanisms have been proposed: (i) thermal (heating) and (ii) non-thermal effects.

Tissue heating is a well-recognized biological effect of RF radiation. RF radiation at high power can rapidly heat biological tissue and cause significant damage. This property of RF radiation at high intensity is used medically to destroy tumour tissue. Microwave ovens use the same principle to heat food. Typical exposures of RF to the general public from commonly used wireless communication devices such as cell phones or Wi-Fi are far below the levels that can produce significant tissue heating and thermal damage.

Non-thermal effects are biological effects resulting from exposure to RF fields that are not a result of tissue heating.[33] Despite a substantial body of research, the mechanism and relevance of non-thermal effects of RF are not well understood. There have been reports of genetic damage including chromosomal instability, gene mutations, and DNA structural breaks[34-37] associated with RF exposure. Some studies have also reported physiological changes, such as altered cell membrane permeability affecting the blood–brain barrier (which enables the passage of potentially damaging substances into and out of cells).[38,39] However, the results of *in vitro* (test tube or culture dish experiments) and animal laboratory studies have not been reproducible (in more than one laboratory) or consistent (within the same laboratory).[40,41] Studies of possible non-thermal biological effects from cell phone use on human brain activity through measurements of brain glucose metabolism were contradictory (one study

showing an increase[42] while another showed a decrease[43]). As well, changes in some electroencephalograph (EEG) parameters were small and inconsistent.[44]

It has not been scientifically established whether non-thermal biological effects could contribute to disease in humans under actual RF exposure conditions above national and international guidelines.[41] Despite the advent of numerous additional research studies on RF fields and health, the only established adverse health effects associated with RF field exposures in the frequency range from 3 kHz to 300 GHz relate to the occurrence of tissue heating and from peripheral nerve stimulation from intense short-term (acute) exposures.

What are the potential health effects from exposure to RF waves?

Risk of cancer

A major concern about the possible effects of exposure to RF is the development of cancer. Some epidemiologic studies have shown an association between long-term and frequent use of cell phones and specific types of brain tumours, especially ipsilateral tumours (located on the same side of the head as the phone was used).[3] For example, a series of studies by Hardell and colleagues found an association between gliomas and cell phone use.[45-49] Gliomas are the most common type of primary brain tumour (starting in the brain), accounting for approximately 75% of all cases. However, primary brain tumours are relatively rare, making up only 1% of all cancers.[50,51] In BC, the 2012 brain cancer incidence rate overall was very low, at 7.25 per 100,000 persons. In the INTERPHONE multi-national case-control study, an increased risk of brain tumours (especially gliomas) was observed only in patients with the heaviest history of lifetime cell phone use (more than 1640 h overall).[52] The authors were cautious about interpreting this result as being conclusive, given errors and biases inherent in the case-control study design. In the CERENAT study, those who used cell phones the longest and most intensely were at higher risk of gliomas.[53] However, despite some positive findings, there has been a lack of consistency in epidemiological studies and meta-analyses as to whether long term and intensive cell phone use is a risk factor for the occurrence of brain tumours.[54-57,58]

It could be expected that brain tumour incidence would increase over time with increasing cell phone use. Canadian published statistics of age-standardized incidence rates between 2001 and 2010 show a slight decrease in annual percentage change (0.1%) for all brain and CNS tumours.[59] BC figures from 1990 to 2009 showed a fairly flat profile for female age-adjusted brain cancer rates and a slightly decreasing slope for males.[60] Data on glioma incidence from these Canadian sources were not available. Age-standardized incidence rates of glioma in the US have been found to be relatively constant over the period of 1992−2008,[61] a finding replicated by many other international studies.[62] However, gliomas of the temporal lobe, a major site for cell phone absorption, were found to have increased at 0.73% per year (95% CI, 0.23−1.23%).[61] Use of ecological studies to detect an effect on cancer from cell phone use is problematic given the long latency period (time between exposure and appearance of tumours) of at least ten years for gliomas and lack of individual exposure ascertainment.

The “possibly carcinogenic to humans” designation by IARC was based solely on cell phone exposure and not from RF fields from other sources.[63] Studies of cancers, other than brain tumours, and their association with cell phone use have mostly been negative. A number of studies, including one from the

INTERPHONE group, have found an association between acoustic neuroma (a benign tumour of the main nerve from the inner ear to the brain) and the highest level of cumulative call time.[64] A study assessing the link between RF exposure from cell phone use and melanomas (an aggressive skin cancer) in the head and neck showed no association.[65,66] A prospective study of British middle-aged women found no increased risk for any type of cancer in association with cell phone use.

The current body of epidemiologic evidence concerning the incidence of cancer attributed to RF exposure has a number of limitations. The case-control and retrospective cohort studies are based on exposures to devices and technologies that are no longer current. Bias is always a concern when historic exposures are linked to contemporary diagnoses: epidemiologic studies can yield incorrect findings through bias in selection of cases or in ascertainment of exposure. Selection bias refers to the likelihood that being included in the study is related to both the exposure and the studied outcome. For example, adolescents concerned about their exposure to RF were more likely to participate in studies involving RF measurements than adolescents not concerned about RF exposure.[67] Exposure to RF has typically been estimated as a binary variable (had used a cell phone for a minimum time or not) or ordinal variable (categories of years used and frequency of use) derived from questionnaire or survey without measurement of actual individual exposure. Recall bias (inaccurate memory of past events) is a particular problem for survey-based study designs such as the INTERPHONE, CERENAT, and the Hardell case-control studies on brain tumours and cell phone use. Ongoing, prospective studies such as the Mobi-Kids and COSMOS studies seek to address some of these insufficiencies and aim to provide additional evidence regarding the possible health impacts of public exposures to RF, including cancer.[68,69] Because cancer outcomes are rare and occur after a long latency period between the initial exposure and occurrence of cancer, such studies are difficult to assemble and involve a large number of subjects followed over an extended period of time.

Reproductive effects

The majority of studies on reproductive effects associated with exposure to RF have assessed damage to sperm cells. This is based on a mechanistic argument which hypothesizes that cell phone exposure has a direct effect on sperm cells when it is placed near the testes (carried on a belt or in pant pockets) or an indirect effect through reproductive hormonal changes. While the balance of evidence does show an association between RF exposure and sperm abnormalities, these effects do not necessarily equate with infertility.[70] A common finding has been that RF exposure is associated with decreases in human sperm quality, especially motility (how well the sperm moves) and morphology (appearance).[71-77] Two meta-analyses of observational studies and laboratory-based experimental studies on human semen showed an association between RF exposure from cell phones and reduced sperm motility and viability (living sperm), whereas the effect on sperm concentration was less clear.[78,79] However there are methodological limitations to these studies, such as poor exposure ascertainment to RF and recall bias in questionnaire-based observational studies. The results of animal studies have been inconsistent and contradictory. Although some laboratory animal studies have demonstrated no effects on sperm quality due to RF exposure,[80-82] other studies have found significant changes in sperm parameters such as motility, morphology, and biochemical properties.[83-86]

Maternal studies concerning pregnancy outcomes related to cell phone use are almost all based on experimental studies of animals. Laboratory studies of rats and mice have not shown any reproductive effects from measured exposure to RF during pregnancy on the number of live or dead embryos, sex ratios, or abnormalities in offspring.[87,88] However, increased mortality of chicken embryos after RF exposure from cell phones has been reported.[89] In general, the animal studies available are highly diverse and inconsistent in methods and often report different outcomes. Epidemiological studies concerning effects on offspring from maternal RF exposure are relatively rare. Findings from occupational studies of physiotherapists exposed to RF through use of short-wave or microwave diathermy (therapeutic heating of body tissues) have been inconsistent.[90] A recent prospective cohort study of pregnancy outcomes among Norwegian mothers assessed levels of cell phone use by surveying both parents by questionnaire.[91] None of the reproductive outcomes studied, including sex ratio, perinatal mortality, low birth weight, preterm birth, small-for-gestational age, or congenital anomalies, were significantly associated with increasing level of maternal cell phone exposure during pregnancy. One study reported a marginally increased risk of perinatal mortality in the offspring of men who testes' had been exposed prior to conception, but these results were deemed biased due to exposure misclassification.[91]

Developmental effects

It has been proposed that exposure to RF affects children more severely as they have thinner skulls, their brain tissues are more absorbent, and their size is relatively small for a given exposure, as compared to adults. For example, the SAR for a 10-year old has been estimated to be up to 153% higher than the SAR for an adult, and absorption of RF in a child's head can be over two times greater than an adult's for the same amount of exposure to RF.[92]

Numerous studies evaluating developmental effects of RF fields on animals have demonstrated teratogenic effects (impaired development of an embryo or fetus) at levels of RF sufficiently high to cause an increase in tissue or body temperature. There is no consistent evidence of developmental effects at non-thermal exposure levels.[93]

There have been a number of studies evaluating the relationship between behavioral problems or brain function deficits in children exposed to RF prenatally or during childhood. Two large cohort studies came to opposite conclusions as to whether children have a higher risk of behavior problems, such as hyperactivity, related to maternal use of cell phones during pregnancy.[94,95] In both studies, bias was introduced from asking, years after the pregnancy, about the mothers' use of cell phones. Although there has been speculation that autism spectrum disorders (ASDs) may be related to RF exposure,[96,97] there is no scientific evidence to support the claim .[98,99] No differences in brain function were found comparing adolescents (aged 11−13 years) exposed to RF typical of cell phones to those who were not.[100]

A multi-center case-control study of European children and adolescents found no relationship between the degree of mobile phone use and the occurrence of childhood brain tumours.[99] A British case-control study on the risk of cancer in young children evaluated exposure to cell phone base stations, with reference to the birth address. No associations were found between estimated RF field exposures from base stations and all childhood cancers considered together, or specifically for brain and nervous system

tumours, leukaemia, or non-Hodgkin's lymphoma. On the other hand, a Taiwan-based case-control study did find a significantly increased risk of all childhood cancers (but not of leukaemia or brain neoplasms) in children under age 16 according to the calculated power from cell phone base stations in their township of residence.[101] In both childhood cancer studies, investigators stressed the need for better exposure assessment methods and further large-scale epidemiological studies to confirm their findings.

Overall, given the limited available evidence, the effects of RF exposure on cognitive development leading to behavioral problems and on childhood cancer, remain inconclusive.

Symptoms

In case reports and cross-sectional surveys, symptoms commonly reported as being associated with RF exposure include insomnia, headaches, tinnitus (ringing or buzzing in ear), fatigue, and dizziness.

The only published study on the health effects of smart meters is a 2014 study describing a case-series of 92 residents from the state of Victoria, Australia, who had submitted complaints through an Australian public web site after the government mandated the installation of the meters.[102] The author concluded that symptomatic complaints were related to the implementation of smart meters. However, the evidence of a link between complaints and the meters is weak in the absence of a comparison group and lack of information regarding the complainants' individual exposures and other factors (such as stress) that may have affected their symptoms.

In addition to individual non-specific symptoms, the syndrome of electrohypersensitivity (EHS) has been attributed to exposures from wireless (cell) phone base stations and other RF-emitting devices. People having EHS suffer from symptoms affecting multiple body systems, such as tingling or burning skin, insomnia, fatigue headaches, nausea, digestive disturbances, and heart palpitations; in some cases, the severity of these symptoms may lead to disability.[103] Experimental laboratory studies often involve double-blinding, in which neither the experimenter nor the subject is aware of the exposure conditions. In such studies, subjects who suffer from EHS and healthy controls are assigned at random to either a 'treatment' group receiving a known exposure to RF signals (from cell phone base station antennae for example) or to a sham exposure group (non-exposure condition). A systematic review of the health effects of exposure to RF from mobile phone base stations concluded that most of the randomized laboratory studies had not detected associations between exposure and the appearance of acute symptoms during or shortly after exposure.[104] A 2015 report combining two laboratory studies assessed whether EHS subjects had greater sensitivity to exposure to RF from cell phone base station antennae than non-EHS controls.[105] The EHS subjects (but not the controls) did have lowered levels of well-being, as determined by symptom scales, when they were aware of being exposed. However, when "blinded" to whether or not they were exposed, well-being was not affected. The investigators suggested that a "nocebo" effect (a detrimental effect on health produced by psychological or somatic factors such as negative expectation of exposure) could explain lower reported well-being when EHS individuals are aware of being exposed to EMF.

Observational studies using surveys in a cross-sectional design are subject to biases such as recall (affected subjects are more likely to remember past exposures), misclassification of exposure (whether

exposed or not and the type and extent of exposure), and a lack of temporality (inability to determine whether the exposure occurred prior to the symptoms). A systematic review of observational cross-sectional studies of people living in the vicinity of cell phone base stations found an association between exposure to RF and symptoms in many of the older studies, but not in the more recent ones.[104] As well, studies with crude exposure assessment based on distance from the RF source were more likely to show health effects as compared to studies with more sophisticated exposure measurements, such as use of dosimeters (devices to measure exposure to radio spectrum waves).[106] For example, a large cross-sectional survey of residents in Germany categorized exposure as distance greater or less than 500 m from the nearest cell phone base station.[107] Subjects living closer to the cell phone base station had a higher summary symptom score. In a follow-up study involving dosimetry in the homes of a sample of the participants, no differences were found in five health scores, when comparing the exposed versus non-exposed subjects, as determined by levels of the mobile telecommunication dosimetry frequencies.[108] The researchers concluded that measured RF emitted from cell phone base stations was not associated with symptoms.

How can one reduce personal exposure to RF?

Although there is little scientific evidence of harm, users of RF devices may wish to decrease their personal exposure to RF by substituting their RF-emitting device with one producing lower or no RF, by using technology to control RF exposure, or by increasing the distance from the RF device. Priority for reducing personal exposure to RF should target personal cell phone use, and cordless (DECT) handsets, as both devices are held close to the head when in use.

There are a number of options to reduce RF exposure from cell phones and RF headsets:

- Spend less time on cell phones; use a wired landline telephone when you have the option.
- Switch off the cell phone when not in use.
- Disable accessory FM and Wi-Fi options when not in use.
- Keep the phone away from the body (i.e., not in pockets) when the phone needs to be powered, but is not in active use. Use the speaker option or an earpiece (headsets) to increase distance between the head and phone.
- Limit the use of wireless earpieces such as Bluetooth headsets as these devices also use RF radiation for transmission.
- Use the text (SMS) option.
- Use phones with low SAR ratings and which emit at lower output power.
- Follow manufacturer's safety instructions.

Exposures from most man-made sources of RF radiation, other than from cell phones or cordless phones, are less intense. Typically, this exposure occurs in the far-field and can be reduced by increasing the distance between one's body and the source of RF radiation. For Wi-Fi systems, access points (routers) should be at least one meter away from where you are working; on the other hand, if access points are far from the terminal devices (such as a computer), a poor connection can increase the output power. In addition, Wi-Fi in the home can be turned off when not in use. Exposure from RF transmitted by a baby monitor is of concern, given the vulnerability of infants to potentially harmful

exposures. A baby monitor that is voice-activated and does not transmit continuously is preferable. Any baby monitor should be placed at least a meter away from the cot.

Conclusion

The use of RF-emitting devices has increased dramatically over the years with the evolution of wireless technologies. There is wider availability of a variety of wireless devices including cell phones, Wi-Fi, laptops, tablets, and Bluetooth. Given their ubiquity and their proximity to users, cell phones are the greatest single source of overall population RF exposure. Ongoing research regarding the potential health effects of RF has not demonstrated clear evidence of impacts on cancer, reproduction, and development; however, at question is whether there are effects of aggregate and ongoing RF exposure on the population's health. Carefully conducted studies on the relationship of acute and chronic health effects with measured aggregate exposures to radiofrequency waves from multiple devices, particularly for children, are needed to better understand whether everyday exposure to these RF sources has the potential to cause harm. It can be expected that exposure to the many different RF sources will increase over time. Wireless communication technology is changing and with it how, where, and how much people are exposed to RF. Regulatory measures do limit total population exposure to RF; however, individuals can choose to apply appropriate measures to reduce their own and their family's exposure to RF radiation, particularly from their use of cell phones.

Authors

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