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How dangerous is the non-ionizing radiation used in mobile communication?

Hansruedi Völkle, Physics Department, University of Fribourg, hansruedi.voelkle@unifr.ch

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The health risks from electromagnetic radiation, in particular those used in mobile communication and the introduction of the 5G technology, raise fears and stimulate controversial discussions. For a better understanding of the effects of electromagnetic radiation used in telecommunications, as well as of possible impacts on human health, some basic knowledge of the physics and biological effects of non-ionizing radiation are presented. International recommendations as well as existing Swiss legislation are also discussed, as Swiss legislation in this area is more severe than in our neighbouring countries. If the Swiss standards are met, then one can, according to current scientific understanding, exclude any health risks with a reasonable and moderate use of mobile communication technologies.

General remarks

The exposure of a person staying close to a source of electromagnetic radiation (i.e. an emitter of non-ionizing radiation, and in particular a cellular phone antenna), depends on a variety of factors. These factors include the intensity of the radiation; the frequency, shape and direction of the antenna's emission pattern (which, for a mobile phone antenna, generally takes the form of a shell); the distance from the antenna; and the attenuation by walls, roofs or windows of buildings. It should be noted that higher frequencies lead beams to become more directional and attenuated, i.e. absorbed, scattered and reflected by interposed objects. The stronger attenuation at higher frequencies on the one side, but the ongoing technical improvements of the sensor sensitivity on the other side, may lead to a moderate increase of the antenna density. The depth at which non-ionizing radiation penetrates the human body also depends on the frequency: for 1 GHz this is a few centimetres, whereas for 10 GHz this is reduced to the millimetre range.

In densely populated urban areas such as cities, exposure includes the total radiation of all mobile phones surrounding an individual, in addition to other radiation-emitting sources also in use in the area. However, the primary exposure to radiation comes from the individual's own mobile phone.

Radiation of cellular phones

Mobile phones are limited in their emission power so that the Specific Absorption Rate (SAR) should not exceed 2 W per kg of organ mass in an exposed person. The SAR value of most commercially-available phones are below 1 W/kg (close to the body). To obtain the Blue Angel label it should not produce more than 1 W/kg (close to the body) or less than 0.5 W/kg (close to the ear). For 0.5 W/kg, the warming of the brain is below 0.1°C. Health consequences will appear only if the body or an organ is heated above 1°C for an extended period of time. On the other hand, the heat felt in one's ear after a long telephone conversation is not caused by the mobile's electromagnetic radiation, but rather the phone's screen and battery as well as the missing cooling by the ambient air.

What frequencies are used for wireless communication and data exchange?

Mobile telecommunication has evolved tremendously in recent years. Not only have the intensities and number of applications increased, but data rates are also soaring from 2G (GSM), 3G (UMTS), 4G (LTE) to now 5G. The frequency band between 700 MHz and 3500 MHz (3500 MHz is used only for 5G) is not only in use for mobile telephony, but also for Bluetooth (2402 to 2480 MHz), WLAN (the bands of 2400-2484 MHz and 5150-5725 MHz; for WLAN-6: 2400 to 5000-6000 MHz) and cordless telephone (DECT), the later in the field from 1880 to 1900 MHz. Other applications like digital radio (DAB), TV and satellite telephony use frequencies ranging from one hundred to a few hundred MHz. Further applications are broadcast programs by satellites at 10 to 20 GHz, whereas the carrier frequencies for radio-relay systems fall between 1 and 86 GHz (Fig. 1). The frequency bands allocated by Swiss authorities to the different provid-

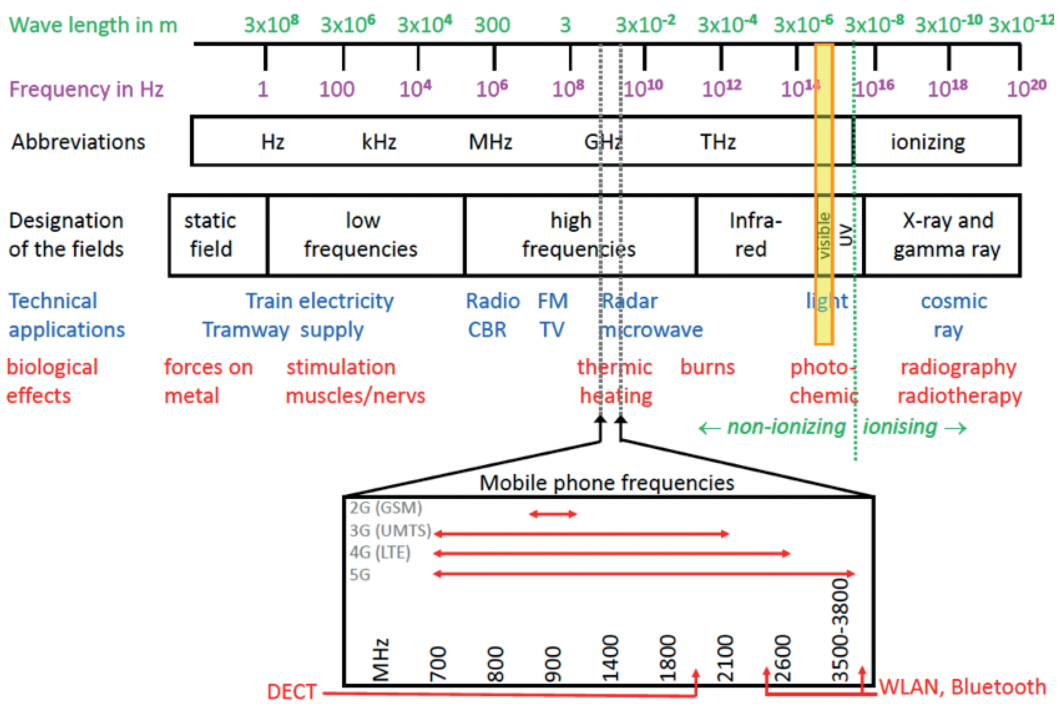

Figure 1: Frequency domain of the electromagnetic spectrum indicated in Hertz (Hz) with the corresponding wavelengths in meters (m). The graph shows the most important technical applications and the biological effects in the different frequency regions. The area used by mobile communication is shown enlarged at the bottom of the graph.

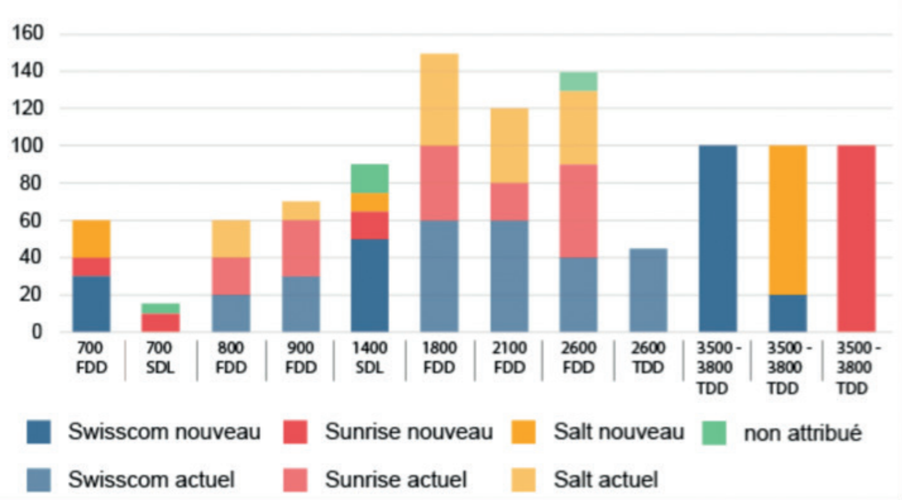

Figure 2: In February 2019 the BAKOM/OFCOM (The Federal Office of Communication) allocated the different frequency domains for mobile communication to the three Swiss operators Salt, Sunrise and Swisscom. Abbreviations: FDD: Frequency Division Duplex = Two radio channels are used for a link; TDD: Time Division Duplex = only one radio channel is used for a link; SDL: Supplemental Downlink = Three radio channels are used for a link.

ers are illustrated in Fig. 2. In 2019, the World Radio Conference identified new bands to be used by mobile telephony which would cover future demand for still-growing data rates. These bands are at 24.25-27.5 GHz, 37-43.5 GHz, 45.5-47 GHz, 47.2-48.2 and 66-71 GHz; after national regulations are put in place, they will be used by mobile phone systems in the near future..

Biological effects of non-ionizing radiation

In the frequency range of mobile phones, thermal effects are considered as the most important ones, but also the possibility of so-called non-thermal effects should be discussed, as some individuals pretend to suffer from them. Such effects are said to affect nerves, brain and metabolism of cells; the consequences could be decreased sleep quality and impaired concentration; damages to genes and other biochemical effects; and even cancer. To date, such effects have not been validated by science at doses below the limits recommended by the ICNIRP [1], whose recommendations are adopted in most national legislations. The health disorders described here, which are attributed to mobile phone radiation by those affected, are very difficult to record with scientific rigor. Evaluating these health disorders qualitatively by proving a cause-effect relationship is challenging, as such studies are based exclusively on the descriptions of psychosomatic symptoms provided by the individuals in question. These studies are therefore mostly non-reproducible.

Moreover, the driving mechanisms are unclear from a biological point of view. Even if such effects can be demonstrated in laboratories at higher doses, they must not necessarily have impact on human health as in a real situation the exposure is for sure below the ICNIRP recommendations. Yet while health risks from exposure to mobile phone radiation have not been validated scientifically, they can also not be excluded with certainty. Reliable statements require long-term studies under realistic conditions.

A selection of biological effects is described in greater detail below.

Attenuation of non-ionizing radiation by matter: The effects of non-ionizing radiation on chemical compounds and biological organisms depend on both the energy of the radiation and its frequency. To produce a physiological effect, the radiation's energy must be absorbed. The attenuation function of non-ionizing radiation or electromagnetic waves by the human body is – apart from the density – similar to the earth's atmosphere. Both are transparent in a wide frequency band, except in the microwave and infrared regions. Responsible for the attenuation is the absorption by the greenhouse gases, water vapor, carbon dioxide, ozone, methane and nitrous oxides. Water vapor in the atmosphere is the most important of these gases, and water constitutes with some 60 and 75% also a dominant component of the human body.

Exposure or dose: The intensity of radiation interaction with biological tissues is given by the dose, i.e. the in a tissue or organ-absorbed radiation energy [J/kg], integrated over the time of exposure. The unit Sv (Sievert) is used for ionizing radiation, whereas the Specific Absorbed energy (SA) is used for non-ionizing radiation. The human body behaves like an antenna: the highest sensitivity is around 50 MHz for adults and around 100 MHz for children. For a

Looking beyond 5G [1]

Even as wireless 5G moves into mainstream, technologists are already looking ahead to the next generation 6G, expected to come on stream in the 2030s. Accessing the terahertz band (sub-millimeter waves) will yield to:

- Extreme high data rate > 100 Gbps exploiting new spectrum bands at 100 x capacity
- Extreme blanket global Gbps coverage, expanded to 10 km in the sky and extended coverage at sea
- Massive connected devices (10 M/km^2) with sensing capabilities and high precision positioning (cm-order)
- Extreme low latency (end to end) of < 1 ms
- Extreme high guaranteed quality of service with 99.99999% reliability
- Extreme low energy and cost: Affordable mmW/THz networks and devices.

1 Source: 2020 NTT DOCOMO, 5G Evolution and 6G (cited from 'Optics and Photonics News', July/August 2020)

1 ICNIRP: The International Commission on Non-Ionizing Radiation Protection is a professional body specialized in non-ionizing radiation protection. The organization's activities include determining exposure limits for electromagnetic fields used by devices such as cellular phones. ICNIRP is an independent nonprofit scientific organization chartered in Germany. It was founded in 1992 by the International Radiation Protection Association (IRPA) to which it maintains close relations. The mission of ICNIRP is to screen and evaluate scientific knowledge and recent findings toward providing protection guidance on non-ionizing radiation, i.e. radio, microwave, UV and infrared. (https://www.icnirp.org/)

person standing upright, a vertical electrical field induces a current flowing from head to feet and vice versa.

Specific Absorption Rate (SAR) is used as parameter to quantify the absorbed energy in human tissue exposed to non-ionizing radiation between 100 kHz and 10 GHz. SAR [W/kg] is the amount of absorbed energy per unit of time and mass of a tissue exposed to radiation.

$$SAR = \int_{Sample} \frac{\sigma(r)|E(r)|^2}{\rho(r)} dr$$

E is the electric field produced in a tissue or organ, with σ representing the electrical conductivity and ρ the mass density. As not all organs have the same sensitivity, the reference mass (1 g or 10 g) must be indicated. To study the heating effect of electromagnetic waves on human bodies, a standard human was defined with a height of 175 cm, a weight of 70 kg, and a total body surface of 1.85 m^2. When exposed to a radio wave radiation of 14 W, the corresponding SAR value is 0.2 W/kg [2].

The ***specific absorption of energy*** (SA), is defined by: SA [J/kg] = SAR [W/kg] x Exposure time [s]. The relative heat capacity per unit mass is C_ρ [J/kg·K] = ΔQ [J/kg]/ΔT [K]. ΔQ is the amount of heat needed to produce a rise in temperature of ΔT [K or °C] = SA [J/kg]/C_ρ. For liquid water at 15°C and atmospheric pressure of P = 101.325 kPa the relative heat capacity is C_ρ {Water} = 4185.5 J/kg·K. Exposing a human body to SAR = 4 W/kg for 15 minutes can cause an increase of 1°C as long as no cooling system such as blood circulation is active. The following are some values for C_ρ [J/kg·K] with density ρ [g/cm^3] in parentheses: skeletal muscle: 3470 (1,06), fat 2260 (0,94), cortical bone 1260 (1,79), spongy bone 2970 (1,25) and blood 3890 (1,06). For experiments, a model of a human body or plastic doll (phantom) is used, filled with material of the same dielectric and absorption data as the body organs. The produced heat by radiation is measured on the phantom by an infrared camera [2].

Surface charges: Low-frequency electric fields can induce surface charges on the body and, consequently, cause surface currents. Important parameters for the exposure effects are the position of the body and its size, the conductivity of skin tissues and the direction of electric vector.

Induced currents, burning, shocking [3]: An electric current induces an electrical and a magnetic field. According to the law of induction in physics, changes in the magnetic flux density cause electric vortex fields. The low-frequency magnetic fields pose more health problems than the low-frequency electrical fields, as magnetic fields are not shielded by the skin. If an alternating magnetic field flows through an electrically conductive object (for example the human body, which contains electrically non-neutral particles such as electrons, ions and polarized molecules), then this field induces eddy currents that move primarily where the interior of the body is particularly conductive (such as blood vessels and well-perfused tissue). The type of induction also depends on the geometrical configuration of the human body and its organs.

Electrical injury is a physiological reaction caused by an electric current passing through the body after contact with electricity. Contact with energized wiring or devices is the most common cause. It depends on the current density, tissue resistance and duration of contact. The effects range from tingling sensations and injuries caused by jerking away or falling, to pain and induced involuntary muscle contractions, to tissue damage and even – at very high currant densities – ventricular fibrillation or cardiac arrest. Inductions in the human body could be more intensive in the lower part of body, as the ankle cross section is lower than the other parts of legs; high current density there may therefore cause burning. In addition, implanted circuits like pacemakers or ear-amplifiers can be damaged by strong electromagnetic fields. In cases of exposure to high voltages, such as those found on a power transmission tower, direct contact may not be necessary to experience an effect because the voltage may ‘jump’ the air gap to the electrical device.

2 Moghavvemi M. et al: *Exposing to EMF*, from the book: *Behaviour of Electromagnetic Waves in Different Media and Structures* (June 2011), DOI 10.5772/931, ISBN : 978-953-307-302-6

3 *Magnetic Resonance Imaging* for medical diagnostics needs high-power magnetic field in order to penetrate body with sufficient intensity. Exposing to such fields are limited by IEC Standards. So, a maximum of 2 W/kg for whole body at 6-minute exposing is recommended.

Interaction of electromagnetic waves with the human body		
Frequencies	***Wavelength***	***Biological effects***
From static electric or magnetic fields to low frequencies		Forces on metals, metallic implants, conductors with currents
0 – 10 MHz	below 30 m	Stimulation of muscles and nerves; maximum sensitivity of the human body is between 20 und 50 Hz
100 kHz – 10 GHz Microwaves: 300 MHz – 300 GHz	3000 m – 3 cm 1 m - 1 mm	Thermal effects (mainly oscillation of water molecules); Maximum sensitivity of the human body (acting as an *antenna*): For adults 50 MHz, for children: 100 MHz
10 GHz – 1 PHz	3 cm – 300 nm	Burns to the skin and body organs
0,4 – 0,8 PHz	750 nm – 380 nm	Visible light = photochemical reactions
0,79 – 0,95 PHz 0,95 – 1,1 PHz 1,1 – 3,0 PHz	380 nm – 315 nm 315 nm – 280 nm 280 nm – 100 nm	UV-A UV-B UV-C
above 3 PHz	below 100 nm	Ionizing radiation: corresponding energy around 10 eV

Table 1

Non-thermal effects: Various possible biological, physiological and/or biochemical effects are included under this heading, such as lowering melatonin levels – which control our immune system's response to cancer and other diseases – or having an impact on genes (DNA), the nervous system and hormonal functions. Growth hormones of glands can also be influenced, which affects children differently than adults. Whether or not non-thermal effects are harmful to human health essentially depends on the type and dose of exposure. Even if previous experiments on non-thermal effects do not always show clear results, a hazard can be excluded on the basis of current scientific knowledge as long as the radiation exposure is below the ICNIRP limits.

Electro-sensitivity

Some people (according to the cited studies, about five percent of the population) consider themselves electro-sensitive. Their complaints include sleep problems, headaches, nervousness, general fatigue, trouble concentrating, tinnitus, nausea and joint pain, among others. It is obvious that these symptoms have an impact on their quality of life, but it is not possible to say with certainty that these problems are caused by electromagnetic radiation. From the current medical perspective, a specific diagnosis of electro-sensitivity is lacking. But it is psychologically understandable that the mere presence of an antenna could trigger aversions and fears that would lead to psychosomatic phenomena. According to the WHO, there is currently no scientific verification that such complaints are linked to electromagnetic radiation exposure. A cause-effect relationship between the symptoms described by electro-sensitive people and electromagnetic radiation can therefore be excluded with a fairly high probability.

Epidemiological studies

As a matter of fact, it is not possible to prove that a substance or technical application is safe. Limit values for intensity or dose can be set only if the effect on biological matter caused by radiation exposure can be measured quantitatively and reliably. Even then, it must be questioned whether this affects health and if yes, whether other risk factors need to be taken into account. Recent epidemiological studies by Martin Röösli [4] *et al.* come to the following deductions: "In conclusion, epidemiological studies do not suggest increased brain or salivary gland tumor risk with M(obile)P(hone) use, although some uncertainty remains regarding long latency periods (> 15 years), rare brain tumor subtypes, and M(obile)P(hone) usage during childhood."

4 Martin Röösli, Susanna Lagorio, Minouk J. Schoemaker, Joachim Schüz and Maria Feychting: *Brain and Salivary Gland Tumors and Mobile Phone Use: Evaluating the Evidence from Various Epidemiological Study Designs* in Annu. Rev. Public Health (2019) Vol. 40: 221-238.

The international recommendations and the Swiss legislation

The Swiss legal bases are:

- The Federal Act on the protection from non-ionizing radiation and noise (***Bundesgesetz über den Schutz vor Gefährdungen durch nichtionisierende Strahlung und Schall***, NISSG of 16 June 2017),
- The Federal Ordinance on protection against non-ionizing radiation (***Verordnung über den Schutz vor nichtionisierender Strahlung***, NISV of 23 December 1999, version from 1 June 2019). This Ordinance fixes exposure limits (***Immissionsgrenzwerte***) for non-ionizing radiation as shown in Table 2, and the so-called precautionary installation limits (***Anlagegrenzwerte***) as shown in Figure 3. The latter apply to locations such as offices, housings, schools, hospitals and homes, etc. and are 4 V/m for frequencies below 900 MHz, 6 V/m above 1800 MHz and 5 V/m in between.

As telecommunications legislation (which includes legislation on ionizing radiation and radioactivity) is ruled on a federal level in Switzerland, cantons or municipalities are not entitled to apply other rules or standards. The cantons are, however, commissioned as executing agencies to control the fulfilment by testing and monitoring (***Kantonale Fach- und Meldestelle***). Despite industry pressure, the Federal Parliament refused a parliamentary motion in 2018 that aimed to modify such legislation by changing the limits for non-ionizing radiation.

The owner of an installation producing non-ionizing radiation must carry out regular measurements, either alone or with institutions commissioned by authorities. These measurements must be performed at locations that are either easily accessible or where high intensity values can be expected. The owner must inform the competent authority of the three points where radiation is most intense, as well as where people might be most strongly affected. In addition, the owner must perform intensity simulations for the area surrounding the antenna. If the simulated values exceed 80 percent of the limit value (*Anlagegrenzwert*), then field strength measurements must be carried out.

The measurements of Prof. Röösli (see box on p. 38) and other similar studies have clearly shown that the exposure of individuals depends not only on the radiation from mobile phone antennas, but on many other sources of radia-

Frequencies	Electric field intensity E_{Gf} [V/m]	Magnetic field intensity H_{Gf} [A/m]	Magnetic flux density B_{Gf} [μT]	Duration of application [min]
for continuous operation				
400 – 2000 MHz	28 – 61	0.073 – 0,16	0.092 – 0,20	6
2 – 10 GHz	61	0,16	0,20	6
for pulsed operation				
400 – 2000 MHz	880 – 1960	2.4 – 5,4	3.0 – 6,7	Duration of the pulses
2 – 300 GHz	1950	5,1	6,4	

Table 2: Frequency bands and intensity limits (Immissionsgrenzwerte) for electric-magnetic fields as established in the Swiss NIS-Ordinance (Verordnung über den Schutz vor nichtionisierender Strahlung) and based on the recommendations of the ICNIRP.

Figure 3: Recommended intensity limits in V/m and subsequent national legislation for the protection from electromagnetic radiation in the domain of mobile communication. Most countries base their national legislation on the recommendations of the ICNIRP (International Commission on Non-Ionizing Radiation Protection). The Swiss NIS-Ordinance (Verordnung über den Schutz vor nichtionisierender Strahlung) fixes, however, two sets of limits: In light colors the so-called Exposure Limits (Immissionsgrenzwerte) and in dark colors the Installation Limits (Anlagegrenzwerte). This unique legislation procedure is based on the precautionary principle, as it is fixed in the Swiss Environmental act (Umweltschutz-Gesetz). Legend: magenta 2100 MHz or above; green 1800 MHz; blue 900 MHz.

tion in their immediate environment. These can include mobile phones belonging to other users, cordless telephones (DECT), WLAN and Bluetooth, which may contribute more to radiation than the exposure from the nearest mobile phone antenna. Individuals are therefore able to control and reduce radiation impact by adhering to the following precautions:

- Do not place the DECT or WLAN base station in a location where you remain for long periods of time, for example near your bed, your home office workplace or the armchair in front of your television.
- Use a mobile telephone with a low SAR value.
- If possible, use wired headphones and microphones.
- Do not use your mobile phone in premises or places with poor reception. In such situations, your phone will increase its emission power to ensure good communication with the nearest antenna.
- When driving a car, use the car's hands-free communication system to minimize radiation intensity – or even better, don't use a mobile phone at all while driving for safety reasons.

Expert judgments

According to the German Federal Office of Radiation Protection (***Bundesamt für Strahlenschutz***), no effects in humans caused by exposures below the ICNIRP limits have been proven so far. The Office based its conclusions on the *Deutsches Mobilfunk Forschungsprogramm* reports. These findings are valid for thermal and non-thermal effects, general health and cognitive functions, risks of cancer and damage to an embryo or a child. According to the Office, these considerations also apply to other applications of non-ionizing radiation, such as 5G. While we do not yet know enough about the long-term effects of radiation beyond 15 years, research in this area should continue. See also the recommendations of the Swiss FOPH [5] in this context.

It is worth remembering the words of Paracelsus: "All things are poison, and nothing is without poison; only the dose makes a thing not poisonous." As with any potentially toxic substance, it is the intensity or the dose that matters. It is the intensity of the electromagnetic radiation that determines whether or not a thermal effect is perceived. It is also the intensity that determines whether radiation is more broadly harmful to human health, either by disturbing or reducing the quality of life, or interfering with the functioning of cells or organs.

How the limits are set

As a general rule, it is not possible to show that an object, substance or technology is not dangerous. Danger can therefore only be assessed through experiments or epidemiological studies that point to what intensity of or exposure to radiation might expose people to side effects. These effects must be reproducible and documented by scientific methods, which will help establish the relationship between exposure to radiation and the likelihood of getting sick or developing cancer. One then determines the corresponding exposure to a certain risk level that is deemed acceptable by the population, taking into account the risks of everyday life. A safety margin is added to this value which is large enough to take into account individual sensitivities. The recommended limits are then obtained, such as those from the ICNIRP [6]. In this procedure, particularly sensitive populations have been taken into account, such as children, the elderly, and possible synergies with other pollutants or harmful substances. In Switzerland – and only in Switzerland – the legislator has added to this an additional layer of security by setting installation limits (*Anlagegrenzwerte*) at ten times lower than the intensity limits (*Immissionsgrenzwerte*) recommended by the ICNIRP. These installation limits are applicable for places with sensitive use such as offices, housing, schools, hospitals and homes. The additional precautionary margin in the Swiss regulation is based on the Federal Act on the Protection of the Environment (***Bundesgesetz für den Umweltschutz***), which calls for lowering emissions to the extent possible as long as such reductions are technical feasible and economically supportable.

Conclusions and recommendations

- What matters is the exposure to electromagnetic fields. Exposure depends on the intensity of radiation at an individual's location and how long that person remains there. The frequency and modulation of the signal, however, play a secondary role, at least for the radiofrequencies used in today's mobile phone networks.
- Switzerland applies the exposure limits (*Immissionsgrenzwerte*) recommended by the ICNIRP while also fixing installation limits (*Anlagegrenzwerte*) applicable for

5 *https://www.bag.admin.ch/dam/bag/de/dokumente/str/nis/faktenblaetter-emf/faktenblatt-smartphone.pdf*

6 See also the 2020 ICNIRP recommendations: *https://www.icnirp.org/en/activities/news/news-article/rf-guidelines-2020-published.html*

places with sensitive use, in accordance with the precautionary principle of the environmental act. These are ten times lower than the ICNIRP exposure limits. It is not expected that the Swiss Parliament and the Federal Council will change the values.

- As long as the recommendations of the ICNIRP are respected, there is, according to current scientific knowledge, no danger to human health with a reasonable and moderate use of mobile communication.
- The Federal Office for the Environment (BAFU/OFEV) will install a monitoring system of non-ionizing radiation and perform calculations of the local exposure density. The data will be publicly available.
- Exposure to electromagnetic radiation is only partially due to mobile phone antennas. Radiation can also include other mobile phones being used in surrounding areas, WLAN, DECT (cordless telephones), Bluetooth and other applications of non-ionizing radiation.
- Everyone's behaviour has a greater impact on personal exposure to electromagnetic radiation than the exposure situation at the place of residence.
- The frequencies which are planned (or implemented) for 5G are already partly used by other applications. 5G is therefore not going to create a fundamentally different exposure situation than the current one. However, it appears that 5G will eventually require a higher antenna density.
- As indicated in the Info Box on p. 34, the 5G network technology is only an intermediate step to the significantly more powerful 6G variant. Since no modern industrial nation can afford not to participate in the development of this technology, it is increasingly important to consider the concerns of many people. This will require further scientific study to better understand the influence of high-frequency radiation on soft matter and on human health. It will also necessitate novel technologies to achieve higher sensitivity of the communication hardware, as well as the development of novel data coding methods to minimize radiation intensities without increasing the transmission error rate.

Exemple of exposure measurements in a Swiss City

Individual exposure to high frequency electromagnetic radiation from mobile communication have been investigated by a project of Prof. Martin Röösli and his team of the Swiss Tropical and Public Health Institute in Basel (Fig. 4). For this study, 115 people living in 12 municipalities in the Canton of Zurich were chosen randomly. The localities have been selected in order to cover all of the different exposure situations that may arise in this area. The study participants were adolescents 12 to 15 years of age, their parents, and young adults 18 to 30 years of age. For a period of 48 to 72 hours they were provided with a portable instrument to record every 4 seconds the intensity of the electromagnetic radiation to which they were exposed and in the 14 different frequency bands used in telecommunications, i.e. between FM radio (87.5 MHz) and that of mobile telephony (2690 MHz). Study participants were also required to complete an activity log and the coordinates (GPS) of the respective locations were also recorded.

The average personal exposure in the study population was 0.18 V/m, slightly higher in young adults (0.22 V/m) than in adolescents and their parents (0.16 V/m). The highest measured average value was 0.42 V/m. The main contributions to the average exposure came from mobile telephone base stations (38 %) and users' individual mobile telephones (35 %), while broadcasting contributions (18 %), WLAN (5 %) and cordless phones (4 %) were less important. The highest exposure was recorded in public transport (train: 0.55 V/m, bus: 0.39 V/m, tramway: 0.33 V/m). In cars, the exposure was 0.29 V/m, outside 0.30 V/m and at the workplace 0.22 V/m. The lowest values were those at school with 0.15 V/m and in houses with 0.11 V/m. The differences between rural and urban residents were relatively small. However, the intensity increases with the rate of urbanization. Individual behavior has a significant influence on exposure, since having a smartphone and how long Internet is used are the dominant factors. On the other hand, the use of a personal WLAN or a cordless telephone at home is of less importance. The study did not find a significant correlation between the exposure of adolescents and that of their parents living in the same household. The authors conclude that everyone's behavior has a greater impact on personal exposure to electromagnetic radiation than the exposure situation at the place of residence.

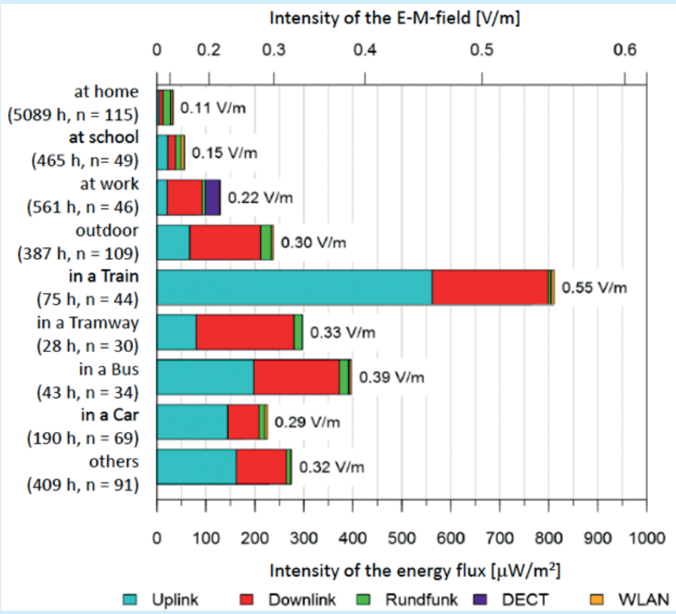

Figure 4: Exposures recorded for inhabitants of the Canton of Zurich by the group of Prof. Martin Röösli: The graph shows the intensities of the electromagnetic radiation from different sources, as well as the hours of exposure and the number of participants. (Uplink = from the user's mobile phones to the antenna; Downlink = from the antenna to the user)