Hazards of electromagnetic radiation

Andrzej Jeleński

After a brief overview of the nature of electromagnetic (EM) radiation and its sources, the article presents selected findings concerning the risks caused by low-frequency EM fields emitted by 50 Hz high-voltage power lines and home appliances. These sources of radiation affect mainly the nervous system and may contribute to the development of cancer. On the other hand, the impact of high frequency EM fields emitted by radio and television transmitters, and mobile phones originate mainly from dielectric losses leading to body heating (thermal hazards) as well as from some non-thermal hazards, which have been less extensively investigated. The remote consequences include: auditory and behavioural effects, blood-brain barrier disruption and cancer. The examples of the recommendations and standards developed by the international and national organizations are also presented.

Key words: electromagnetic field, high voltage power lines, mobile phone base stations, mobile phones, radio and TV transmitters, household appliances, leukaemia, brain tumours

Zagrożenia przez promieniowanie elektromagnetyczne

Po krótkim omówieniu źródeł i charakteru promieniowania elektromagnetycznego przedstawiono wybrane wyniki badań zagrożeń powodowanych przez pola EM niskiej częstotliwości emitowane przez linie energetyczne wysokiego napięcia 50 Hz i sprzęt AGD. Ich głównym efektem jest oddziaływanie na układ nerwowy i wpływ na choroby nowotworowe. Z kolei efektem pól EM wysokich częstotliwości emitowanych przez nadajniki radiowe, telewizyjne, telefony komórkowe są głównie straty dielektryczne prowadzące do nagrzewania ciała (zagrożenia termiczne) oraz słabiej zbadane zagrożenia nietermiczne. Do tych ostatnich należą: efekty słuchowe, behawioralne, zakłócenia działania bariery krew-mózg, choroby nowotworowe. Przedstawiono również przykłady zaleceń i norm opracowanych przez międzynarodowe i krajowe organizacje.

Słowa kluczowe: pole elektromagnetyczne, linie wysokiego napięcia, stacje bazowe telefonii komórkowej, telefony komórkowe, nadajniki radiowe i TV, sprzęt AGD, białaczka, nowotwory mózgu

DOI: https://doi.org/10.34769/0732-q803

1. Introduction

Since the beginning of mankind, numerous threats have become the bane of humanity, but the struggle against those dangers has also been a stimulus for constant technological progress and the development of civilization. Initially, the forces of nature were the main enemy, but recently they have been replaced by the effects of human activity. Increased urbanization and industrial activities have caused growing environmental pollution. Exhaust gas, smoke and sewage that are polluting the air and water, as well as the intensive animal farming and excessive fertilization leading to soil poisoning, have become the obstacles to the further balanced development of the societies. Environmental pollution has been called "the threat of the 20th century". It has become a matter of public concern and international organizations have taken actions and resolutions in order to counteract them.

Electricity was discovered in the 18th century. At first, the effects of this "new force" were utilized by magicians called "electricians". It was not until the beginning of the 19th century that great potential for its practical use was revealed. The inventions created by Edison, Tesla and Bell established this "new force" as the basis for the rapid development of civilization. Within the 20th century the societies became totally dependent on electricity. Each power outage is treated as one of the biggest disasters.

In the 21st century, in the so-called information society, this electromagnetic field (EM field) has become a key for further progress, allowing for the creation, transfer, processing and storage of information. The internet and computers are now the principal work tools. The number of the sources of EM field is also growing rapidly: home

[1] *Łukasiewicz Research Network - Institute of Electronic Materials Technology*, 133 Wólczyńska Str., 01-919 Warsaw, Poland e-mail: amjelenski@gmail.com

appliances, mobile phones, Wi-Fi, TV sets as well as the currently emerging remote control systems for the so-called "smart home" and health monitoring, and 5G mobile telephony. All of them will cause a further increase in the intensity of EM fields in the surrounding environment and the still growing demand for electricity will result in greater radiation from the overhead power lines.

The first reports about the possibility of EM field impact on the human body come from the late 18th century, when it was discovered that the frequency of about 1 MHz acting on a human field, causes muscle spasms (non-thermal interactions) [1]. In the mid-nineteenth century, the studies of Duchenne - considered the father of electrotherapy - began the utilisation of high-frequency electric currents for therapeutic purposes [2]. In 1892, d'Arsonval discovered that using magnetic field with a frequency of 0.5-1 MHz acting on human body can cause tissue heating (thermal effect) [3]. Since then, two research trends have been developing independently of each other: tests of the possibility of using electromagnetic fields for medical purposes (diathermy, magnetic therapies, magnetic resonance imaging), and the examinations of the risks to human health affected by these fields. This study is devoted to the latter trend.

2. Electromagnetic field

EM field, along with the gravitational field and short-range strong and weak interactions, belong to one of four fundamental fields in the universe. EM field is related to the motion of the electric charge carriers caused by the natural phenomena (atmospheric discharges, solar radiation) or by the man-made devices (power lines, radio stations, mobile telephony devices, television, radars or home appliances). The hazards caused by EM fields are usually described as the threats due to non-ionising radiation ranging from the static field to the infrared (i.e. with frequency from 0 to 300 GHz) (Fig. 1). The hazards originating from EM fields with higher frequency, i.e. ionising radiation, will not be discussed in this paper.

The fundamental parameters of EM field are: electric field intensity - E [V/m] or electric induction D [C/m^2] = εE, where ε is the electric permittivity characteristic of a given medium and magnetic intensity H [A/m] or magnetic flux density (magnetic displacement or magnetic induction) B [T] = μH, where μ is magnetic permeability of a medium. A related parameter is power density, i.e. a surface density of a flux of EM field energy S [W/m^2], which is a product of the induction values of both fields. The heating of the objects present in an EM field depends on the S value. Through a body placed in the electric field or under the applied voltage U [V] the electric current will be flowing, characterised by the intensity I [A], proportional to the specific conductance (electrical conductivity) σ [1/Ωm] = $1/\rho$ [Ωm], where ρ is the electrical resistivity of a medium.

3. Sources of electromagnetic field

The most common sources of low-frequency EM field are high voltage power lines and transformers, as well as home appliances. The magnitudes of EM fields emitted by these devices are given in Table 1.

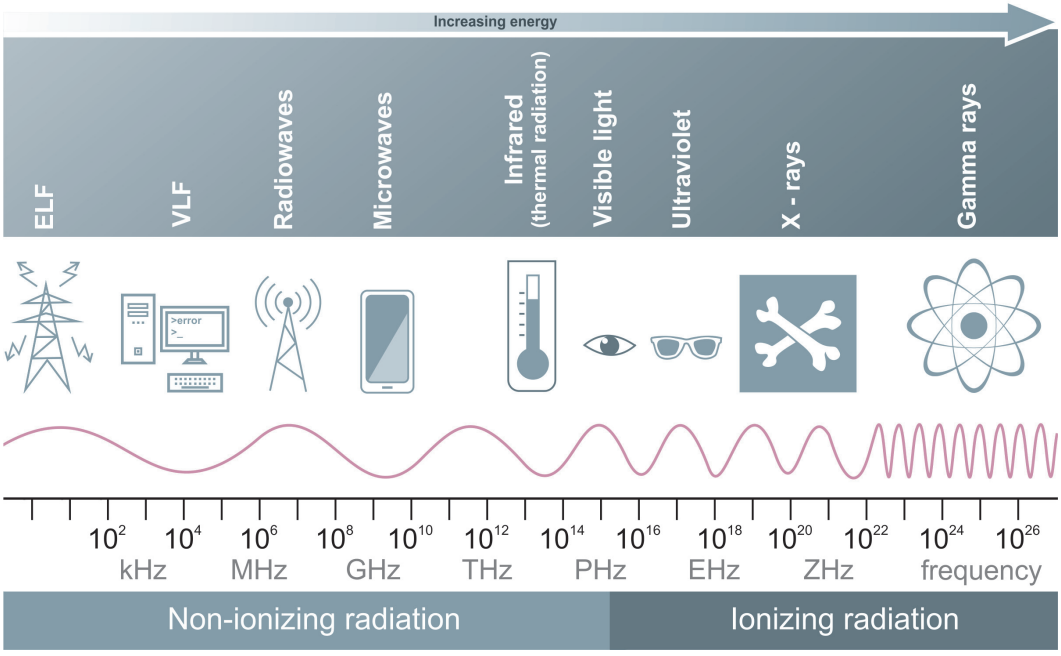


Fig. 1. Frequency spectrum of electromagnetic field.
Rys. 1. Widmo częstotliwości pola elektromagnetycznego.

Tab. 1. Typical values of EM field with 50 Hz frequency, generated by power lines and home appliances [4].
Tab. 1. Typowe natężenia pola EM o częstotliwości 50 Hz generowanego przez linie przesyłowe i sprzęt gospodarstwa domowego [4].

Radiation source	Electric field (V/m)	Magnetic field (μT)	Comments
Power lines 400 kV	1000 - 10000	8-40	At a distance of 25 m
Electric train or tram (maximum)	300	50	Inside
Microwave oven, 850 W, 2450 MHz	2000		Inside
Microwave oven, 850 W, 2450 MHz	<1.5	4- 8	At a distance of 30 cm
Electrical wiring	100	0.2	Indoors
Electrical equipment	10 - 250		At a distance of 30 cm
Stereo receiver	180	1	At a distance of 30 cm
Iron	120	0.12 - 0.3	At a distance of 30 cm
Refrigerator	120	0.01 - 0.25	At a distance of 30 cm
Toaster	80		
Hair dryer	80	0.01 - 7	At a distance of 30 cm
Colour TV set or computer screen	10-60	0.01 - 0.15	At a distance of 1 m
Coffeemaker	60		
Vacuum cleaner	50	2 - 20	At a distance of 30 cm
Background radiation	1 - 10	0.01-1	Indoors - background
TV monitor	1 - 10		At a distance of 30 cm
Electric heater	8	0.15-0.5	At a distance of 30 cm

Rafai and Hakami [4] measured the magnetic field intensity in the urban environment. These measurements confirmed that the sources of the greatest EM fields, exceeding 2 μT (the level permissible in the USA in the places of residence) are found nearby power lines, while the strongest radiation of the household equipment originates from: electric heaters, vacuum cleaners, hair dryers (up to 20 μT) and such power tools as drills and power saws (up to 30 μT).

At present, the most common sources of higher frequency EM radiation are radio stations and mobile telephony base stations, which generate the fields that can surround us everywhere. Two aspects should be considered separately when evaluating the radiation exposure, namely: the hazards of the radiation generated by antennas of radio stations or base stations, and the threats originating from the mobile phones themselves,



Fig. 2. High voltage power lines.
Rys. 2. Linie wysokiego napięcia.

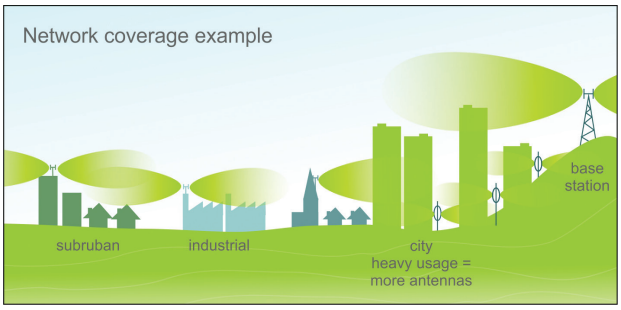


Fig. 3. Beams of radiation of antennas [5] in a modern city.
Rys. 3. Wiązki promieniowania anten [5] we współczesnym mieście.

which even though being much weaker radiation sources are usually kept close to an our body.

Figs. 2 and 3 depict a modern urban landscape, showing a variety of numerous sources of EM field and typical beams of their radiation. The antennas of television, mobile telephony networks or other communication systems, remote control and monitoring have become an integral part of the scenery of the cities. Even if the magnitude of radiation emitted by each separate antenna meets the standards, in certain places the cumulative intensity of various fields may exceed the maximum permissible safety level. The maximum radiation of antennas should be directed high above the roofs of the buildings. However, in the case of the newly-built tower blocks the residents living on the upper floors can be exposed to excessive radiation.

An exemplary spectrum of EM field, measured in the outskirts of Lublin, is shown in Fig. 4.

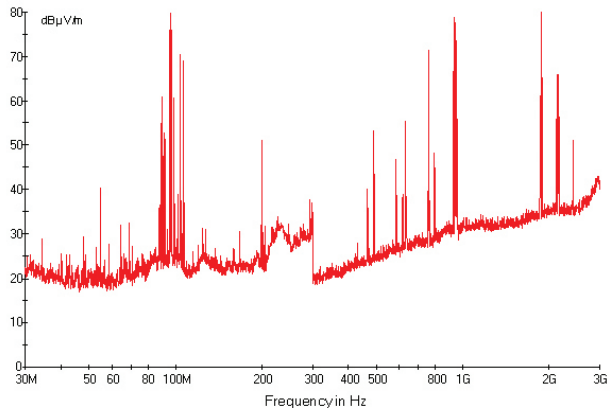


Fig. 4. Spectrum of EM field ranging from 30 MHz to 3 GHz, measured in Lublin, on Nadbystrzycka Street, using an ESCI3 instrument produced by Rohde&Schwarz [5-6].
Rys. 4. Widmo pola EM zmierzone w Lublinie na ul. Nadbystrzyckiej miernikiem ESCI3 firmy Rohde & Schwarz w granicach 30 MHz do 3 GHz [5-6].

Fig. 4 demonstrates that a cumulative radiation level of a suburban street does not exceed several tens of mV/m, however it can be much higher in the vicinity of antenna clusters in other quarters of large cities.

An additional factor that can alter considerably the local exposure values concerns the multiple reflections of radio waves from the surrounding buildings. Fig. 5 shows that these reflections may markedly increase or decrease the local field values to such an extent that for the build-up areas direct measurements are needed to determine the radiation level in places where it can affect the people.

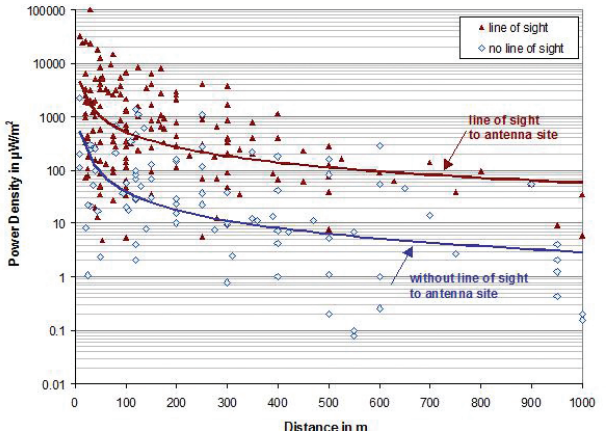


Fig. 5. Levels of radiation power density from a GSM mobile telephone station as a function of distance in case of or without a direct visibility [7].
Rys. 5. Poziomy gęstości mocy promieniowania stacji telefonii komórkowej GSM w funkcji odległości w przypadku widoczności bezpośredniej i bez niej [7].

4. EM field impact on the body

EM fields generated by electrical equipment can have a significant impact on humans. The following three main groups of methods are applied for the examination of the influence of non-ionising radiation on human organism:

1. **Biological tests**, evaluating the effects of the exposure to EM field of a given wavelength and intensity. The tests are performed on volunteers or animals (*in vivo*), as well as on various tissue samples (*in vitro*).

2. **Dosimetric examinations**, which enable finding out a connection between the intensity of external and internal fields inside an organism, directly affecting individual organs or influencing particular processes. These methods involve:

a) calorimetric methods - consisting in the measurement of temperature rise of an object placed in a calorimetric system

b) absorption methods - consisting in the measurement of EM field power absorbed by the objects placed in waveguides

c) numerical methods - consisting in the calculations of the magnitude of EM field inside an object with the

assumed parameters of that object being possibly close to the real ones.

3. **Epidemiological studies**, which are based on a comparison between the population exposed to EM field and the similar population not influenced by that field. Of course, such an investigation can be conclusive only on condition that it has been ensured that all other factors affecting the health were identical for both groups, which is difficult to ascertain in the case of a long-lasting research. The epidemiological methods, however, are the only way that allows the examination of the long-term effects of exposition to EM field. They may also give an answer to whether the disorders in functioning of the body caused by EM field are only temporary or will result in a permanent damage to health.

5. Direct effects of EM field

Adverse health consequences of the exposure to EM field are different for different ranges of frequency. Staying and, especially, moving in a static magnetic field may cause nausea. For the frequencies lower than 100 kHz the field penetrates the organism and affects the senses, nerves and muscles. Directs hazards can be due to the currents flowing through the body after touching a live wire, they

Tab. 2. Magnetic flux density values (μT) of a field emitted by various sources. The recommended safe level is 0.05-0.25 μT [4].
Tab. 2. Natężenia emitowanego pola magnetyczne (μT) przez różne źródła. Rekomendowany bezpieczny poziom 0.05-0.25 μT [4].

Source	Distance: up to 10 cm	1 m
Household food mixer	50 - 220	0.03 -0.3
Washing machine	8 - 200	0.01 - 0.4
Coffeemaker	6 - 29	0.01
Computer	4 - 20	0.2 - 0.5
Fluorescent lamp	400 - 4000	0.01 - 0.5
Hair dryer	60 - 20000	0.01 - 0.6
Electric heater	100 - 50	0.01 - 0. 25
TV set	5 - 100	0.01 - 0.6
Vacuum cleaner	230 - 1300	0.3 - 4.0
In a Boeing 747 aircraft	on the average 0.5	

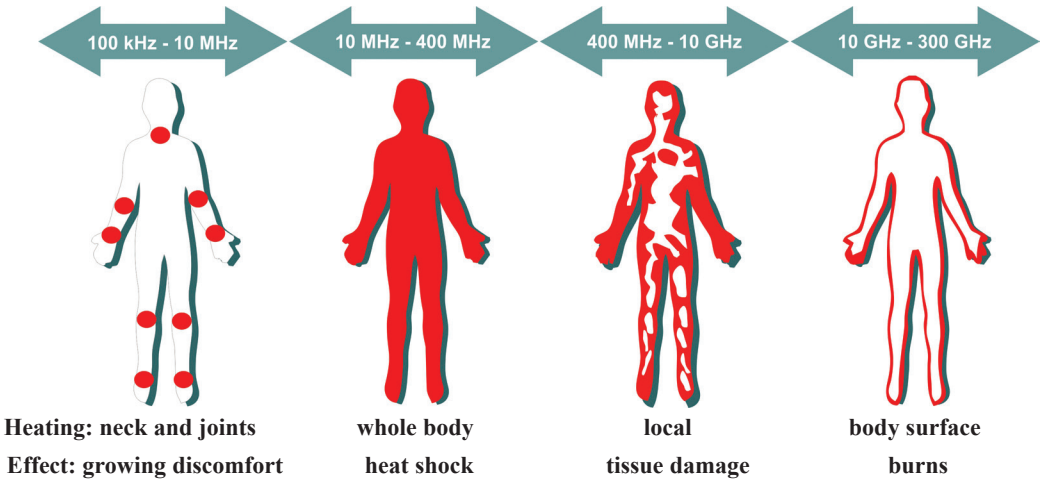


Fig. 6. Thermal effects of EM field with frequencies higher than 100 kHz [9].
Rys. 6. Oddziaływanie termiczne pola EM o częstotliwości większej od 100 kHz [9].

are also due to prolonged exposure to the high voltage power lines or the vicinity of some home appliances [4]. Table 2 lists the safe distance values from various sources of EM radiation with 50 Hz frequency.

The hazards caused by the radiation of physiotherapy equipment for people operating that equipment and for the patients with implants sensitive to EM field were discussed by Karpowicz and Gryz [8].

In the radio frequency range (above 100 kHz) the mechanism of cell stimulation by the induced currents becomes less important and the principal effect of EM field energy absorption concerns a direct heating of tissues, particularly joints and muscles.

For frequencies higher than 400 MHz, the organism penetration depth by EM field decreases with the increasing field frequency, leading only to the local tissue damage. With a further frequency rise the heating effects are limited to a body surface causing burns (Fig. 6).

The generally accepted measure of thermal effects of EM field with a frequency ranging from 100 kHz to 10 GHz is SAR coefficient (*Specific Absorption Rate*), which describes the rate of energy absorption by a mass unit of a human body:

$SAR = C\Delta T/\Delta t$

C - specific heat, ΔT - temperature increase caused by EM radiation during a period of Δt.

SAR can also be expressed as:

$SAR = \sigma E^2 / \rho$ (W/kg)

σ - sample electrical conductivity [1/Ωm], E - RMS electric field (root-mean square value) induced in a tissue (V/m), ρ - sample density (kg/m^3).

SAR determination is based on the measurements of EM field power absorbed by a standard dummy man, named SAM (*Specific Anthropomorphic Mannequin*). The power value of 4 W/kg, resulting in the increase in the mannequin temperature by 1°C (accepted as safe for an organism) has been defined as a maximum permissible SAR value. Another way of SAR determination is to use computer models, where a variety of factors can be analysed, which would be difficult to be taken into account using the mannequins. An alternative method, instead of absorbed power or temperature measurements, is the determination of EM fields induced inside the tissues, called in EU "Exposure Level" EL (Polish acronym: PO – Poziom Oddziaływania, which literally means "impact level"). However, these level is difficult to be measured. In practice the EM fields surrounding the examined object are measured. They are called "hazard levels" (Polish acronym: PN – Poziom Narażenia, meaning "exposure level"). The relations between these two aforementioned parameters (PN and PO) and SAR are determined in the specialised laboratories.

According to EU nomenclature, the highest exposure limit (Polish acronym: GPO – Graniczny Poziom Oddziaływania, "limiting impact level") believed to be safe for health is called ELV (Exposure Limit Value). A corresponding value of the maximum external field (Polish acronym: IPN – Interwencyjny Poziom Oddziaływania) is denoted by EU nomenclature as AL (*Action Level*). The magnitudes of EM fields leading to SAR limits depend on frequency. Therefore, GPO and IPN values are given in the form of tables or diagrams.

Because the mannequins do not represent children but only an adult man, the authors of standards taken large safety margins (SAR reduction factor).

The amounts of energy absorbed in various parts of a body can markedly differ, as it occurs in the case of people being in direct contact with the EM radiation

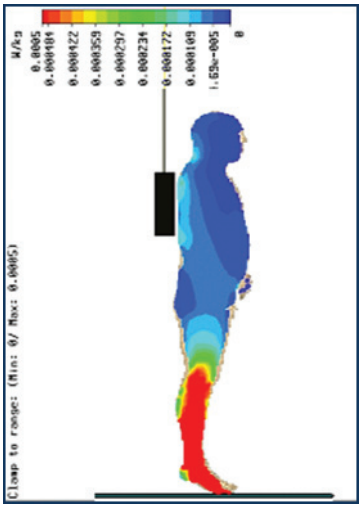


Fig. 7. SAR of a short-wave transmitter placed on the back of a grounded person [5].
Rys. 7. SAR nadajnika krótkofalowego na plecach uziemionego człowieka [5].

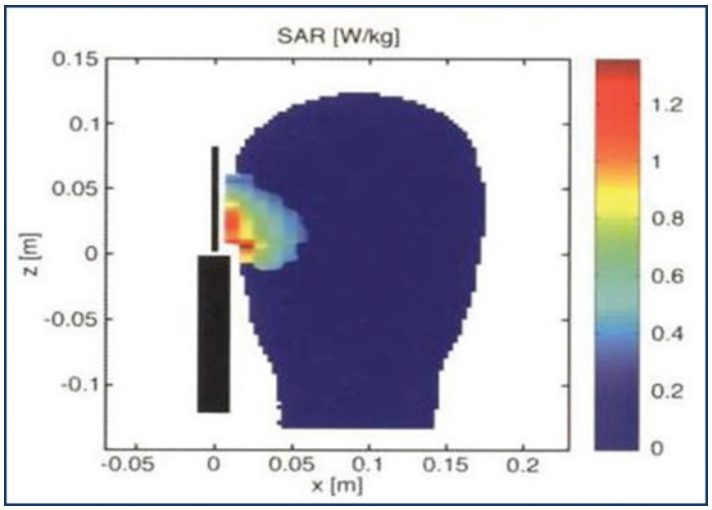


Fig. 8. SAR of a mobile phone [10].
Rys. 8. SAR telefonu komórkowego [10].

source such as short-wave transmitters or mobile phones (Figs. 7 and 8). For the determination of the permissible exposure level local SAR values are used.

The most common close to the human body sources of high-frequency EM fields are mobile phones. SAR values of the mobile phones available on the market are 0.2-2 W/kg and their radiation intensity may even reach 50 V/m. Usually, SAR values are in the range 0.4-0.9 W/kg. When a GSM mobile phone (power of 1 W) is connected with the network the power density at a distance of 1 cm from the phone can exceed 300 mW/cm^2. Increasing the distance to 30 cm leads to the power density decline to 0.3 mW/cm^2. The exposure to a mobile phone radiation is not limited to the time the actual phone calls. Today, the mobile phones of LTE (4G) technology, serving as routers and containing many transmitters are characterised by permanent radiation. We usually carry our phone in a pocket of a shirt or trousers and do not take into account the fact that it can be transmitting constantly.

The absorption of EM field by an organism becomes also greater around the resonant frequencies of a human body. For adults, these values are around 35 MHz when the body is grounded and around 70 MHz when the body is insulated from the earth. Additional resonances for around 1 GHz occur at the body surface. When a person is staying in EM field with such frequencies, the amount of absorbed energy rises 5-10 times. The resonances can also occur in the particular parts of the body. A conversation with the phone next to the ear results in a significant local exposure of the head. For adults, the penetration depth of the microwave radiation into the interior of the tissues is around a few centimetres and can reach some brain structures, especially the temporal lobe. The resonant frequency of an adult's head is around 400 MHz, while for a small child's head it is around 700 MHz, which is close to the GSM operating frequency. The investigations have revealed that the children are the most susceptible to the influence of EM fields [10], which can be exemplified by the simulation results of the head penetration by EM fields for various age groups (Fig. 9).

6. Remote effects of the exposure to weak EM fields

Direct, short-term exposure to weak EM fields is imperceptible for people. However, long-term exposure to weak EM fields can lead to chronic fatigue or even illness, as demonstrated in the reports given below.

a) Threats from low-frequency EM fields

Numerous reports describe detrimental effects of the long-term impact of EM fields being weaker than those accepted as safe. Ahlbom et al. [11] established that the relative risk of cancer was doubled (from 1.27 to 3.31) for the children living in the houses near the power lines where the magnetic field exceeded 0.4 μT in comparison with the control group of children living in the houses where the magnetic field was lower than 0.1 μT. Epidemiological research carried out in Sweden by Feychting and Alhbom [12] revealed an increased incidence of leukaemia for the children residing in the fields greater than or equal to 0.2 μT. Also Draper et al. [13] found that the relative risk of leukaemia was 1.67 times higher for the children living closer to high voltage power lines than 200 m and 1.23 times higher for the distances 200-600 m,

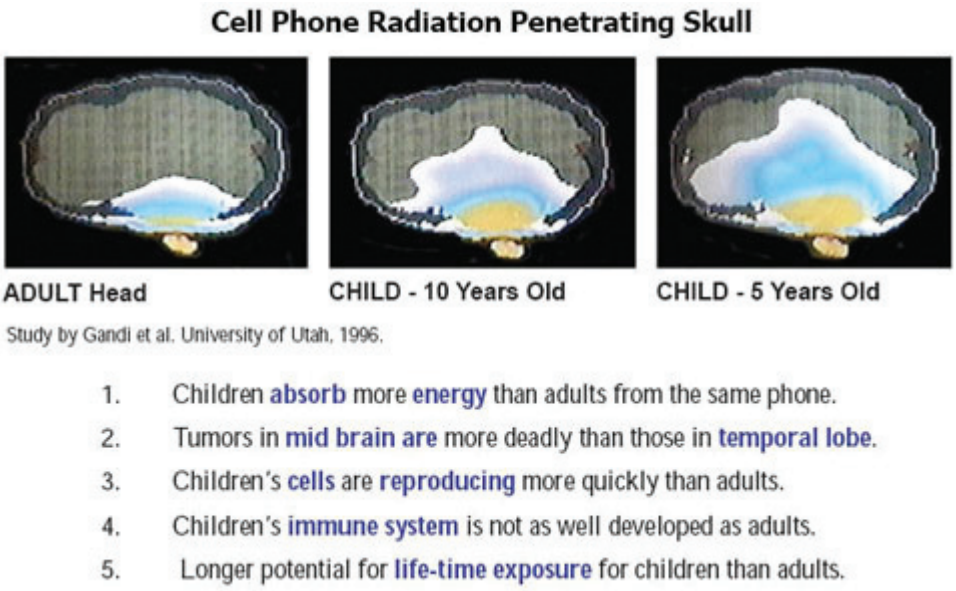


Fig. 9. Simulation of EM field penetration depth from a mobile phone placed close to the head [10].
Rys. 9. Symulacja głębokości wnikania pola EM telefonu komórkowego umieszczonego blisko głowy [10].

as compared with the group of children living at distances greater than 600 m. These researchers, however, did not observed such a correlation for other types of cancer.

Feuything et al. [14] found that the risk of death due to Alzheimer's disease for people staying in EM fields was 2.3 times higher than for the control group.

Kanai et al. [15] demonstrated that staying in electric fields with frequency ca. 20 kHz and intensity greater than 50 mV/m caused slight problems with optical signal processing and motor coordination. The weakness of these studies lies in short periods of the presence in the field and in small number of measurements.

The BioInitiative Report [16] summarizes the results of 69 articles published in the years 2007-2012, devoted to the prolonged effects of weak EM fields. The report has shown that 64 articles (93%) indicated adverse effects, while 5 articles (7%) did not contain such statements. The report also includes tables summarizing the conclusions drawn by particular authors. Fig. 10 illustrates the threats arising from long-term stay in a power line field.

b) Threats from high-frequency EM fields

Many scientists find it wrong not to ignore the effects of the modulation, in particular pulse modulation, of the signals emitted by base stations and mobile phones. Numerous in vivo and in vitro studies carried out since 1975 in USSR/Russia [17] have revealed that the EM field modulation causes a significant increase of the non-thermal effects, while according to Frey [18] certain effects may even not occur for non-modulated fields.

The examples of the non-thermal effects of the human exposure to weak EM fields are given below:

• **microwave auditory effect** (microwave hearing effect), observed for EM pulse radiation. When the peak value of the radiation intensity is very high, this effect can occur in spite of low values of the average power. Frey [18] describes the effect of microwave hearing, appearing already for the exposure to radiation with the average power density value of 2 μW/cm^2 (i.e. much lower than the permissible value according to the standards being currently in force). Frey and Messenger [19], as well as Elder and Chou [20] have demonstrated that this effect does not depend on the average value of EM field but on the amplitude of the pulses and that its source comes from the thermoelastic pressure waves induced by microwave radiation. The consequences for low peak values should not be hazardous to health, similarly to the effects of the acoustic waves.

• **blood brain barrier (BBB) function disorder**. BBB enables the necessary substances to be selectively transported from the blood to the cerebrospinal fluid and it also protects the nervous tissue from the harmful agents existing in the blood. In the presence of EM fields the diffusion of all the molecules through BBB is enhanced. This diffusion, causing also the removal of calcium ions from the brain, leads to calcium metabolism disorders, which may, for instance, result in headache [21]. According to the studies performed by Salford et al. [22] it is possible to observe only remote effects of the exposure to EM radiation. The authors demonstrated that after 2-hour exposure of rats to a GSM phone with a power 0.2 mW/kg (i.e. much smaller than the permissible SAR value), a significant rise in BBB permeability appeared no sooner than after 28 days, while neuron damage appeared after 50 day. However, the literature reports on the remote harmful effects of the EM radiation on the central nervous systems or the brain are ambiguous [23-24].

• **threat of cancer due to a prolonged use of mobile phones**. The investigations carried out by Hardell et al.

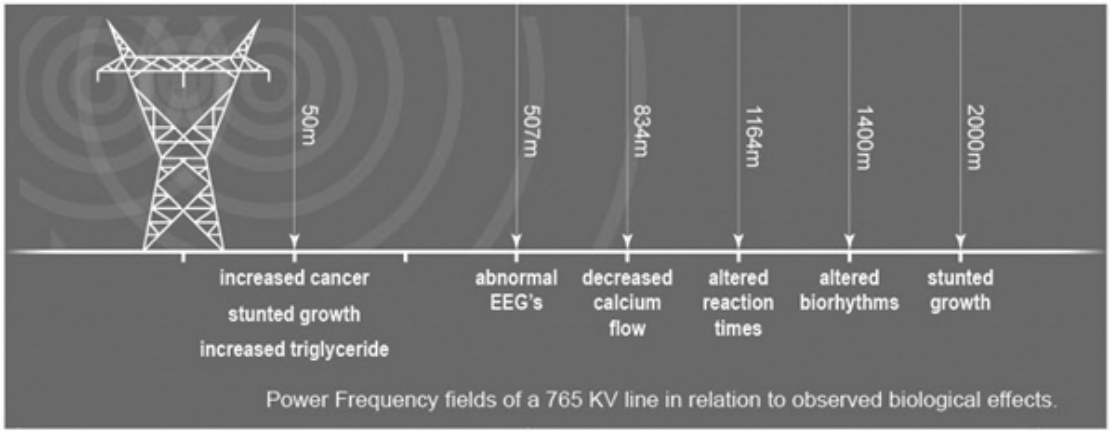


Fig. 10. Threats from the high voltage power lines [16].
Rys. 10. Zagrożenia przez pole linii wysokiego napięcia [16].

[25a-d] showed that in the case of a bilateral use of cell phones (30 minutes per day for 10 years on average) the risk of glioma increased by 1.2 times and even doubled in the case of an use of the mobile phone always on the same side of the brain. The risk of acoustic neuroma for these users increased by 1.3 and 2.4 times, respectively. Similar dependencies are described by Pareja-Peña et al. [26].

Hocking [27a] demonstrated the increase in the incidence of leukaemia by 1.58 times and a doubled mortality among the children living in a zone close to the radio television transmitters (up to 4 km) in comparison with the zones more distant (of 4-12 km). The author's next results published in 2000 indicated that the chance for recovery from leukaemia for the children living in the distant zone were twice as good as for the children living in the zone close to the transmitters [27b].

There are many more articles devoted to the aforementioned dangerous for health, athermal effects of staying in EM field. The summary of the conclusions drawn from these data can be found in the review articles by Rafai et al. [4], Batoli et al. [28] and in the SSM (Swedish Radiation Safety Authority's) report [29]. The authors, describing the impact of EM fields on humans and animals, stress the fact that the results obtained so far are not completely consistent. Further studies are needed to determine the ultimately safe maximum magnitudes of EM fields.

7. International legal standards

The protection against EM radiation has also been dealt with by the European organisations. Experts from the National Radiological Protection Board (NRPB) in Great Britain have analysed the results of the epidemiological studies on a group of children living near the power lines and confirmed the increased risk of leukaemia. However, they consider staying in magnetic fields not exceeding 0.4 μT [30] safe.

In 2011, the International Agency for Research on Cancer (IARC) [31a] changed the classification of the damaging effects of radio waves into "possibly carcinogenic" and stated that "for the users of cordless phones limited adverse effects are possible in the form of glioma and acoustic neuroma, resulting from the exposure to EM field with radiofrequency. On the other hand, the research conducted so far are not sufficient to draw conclusions about other types of cancer." A detailed discussion on the results of the investigations leading to such statements can be found in the IARC monograph [31b].

In the same year 2011, the Scientific Technology Options Assessment (STOA) - a body of the European Parliament - asked the EU Commissioner for stricter standards regarding protection of people against EM field with radiofrequency, stating that: "on the basis of the results of the studies on the radiation impact on human health, the limit value for the places of people's presence should not exceed 1000 $\mu W/m^2$ (0.1 $\mu W/cm^2$), taking into account all cumulated sources of radiation. However, the permissible long-term averaged level, having considered the safety factor, should not be higher than 100 $\mu W/m^2$ for the places of people's long stay. Particularly stringent standards should be applied with regard to sleeping places, the places of prolonged stay of children, neonates, pregnant mothers, the elderly as well as people with serious diseases and the chronically ill. In such cases, the permissible long-term averaged level should not exceed 10 $\mu W/m^2$".

All the restrictions concerning the permissible levels of EM radiation lead the increased costs of energy and telecommunications companies and, in consequence, to the rise in the price of services. As long as the current standards are in force, these companies do not have to replace the overhead lines with the more expensive underground cables or to increase the number of base stations. Despite the overwhelming number of the results indicating the existence of specific threats due to a prolonged exposure to weak fields, the International Commission on Non-Ionising Radiation Protection (INCIRP), appointed and funded by the European Union and the governments of several countries, has considered the prolonged effects of the exposure to EM field as insufficiently evidenced. In the 2010 recommendations, regarding the maximum permissible GPO and IPN values, it is stated that the decisions were made on the basis of the research results "supported by well-established scientific evidence on the connections between the immediate direct biophysical effects and the exposure to electromagnetic fields" [32a]. In March 2020, the ICNIRP modified the recommendations taking into account the progress of knowledge about the dependence of the body temperature on the EM field and the differences in thermal effects of the exposure to the near and distant EM fields [32b]. According to these recommendations, the maximum SAR value in the safe zone (for the general population) averaged over the whole body is 0.08 W/kg. On the other hand, the local SAR values (averaged over the volume of a cube with the mass of 10 grams of a tissue) are 2 W/kg for the head and 4 W/kg for the limbs. The resulting EM field maximum values in the safe zone are shown in Figure 11.

The existing Directive of the European Parliament of 2013 [33], specifying the minimum requirements for the workers' health protection against the impact of EM fields stipulates that: "the scope of this directive does not involve any suggested effects of the prolonged exposure to electromagnetic fields, because currently there is no well-established scientific evidence of the existence of a causal connection in this respect" and: "some medical equipment interference, especially pacemakers, may occur at levels not exceeding the IPN values, and therefore they should be the subject to proper precautions and protective measures."

Many European countries have adopted the standards based on the directives of the European Parliament.

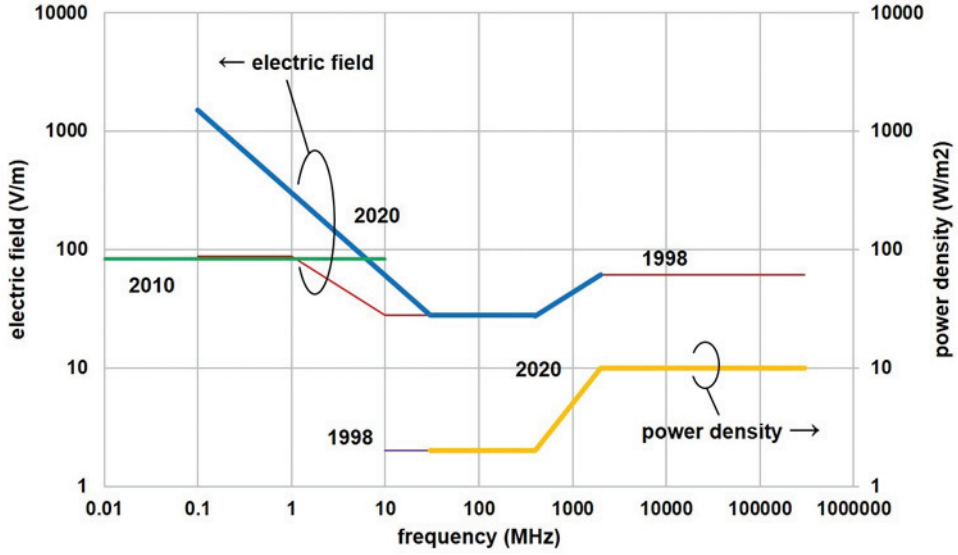


Fig. 11. Maximum values of power density and electric field in a safe zone (for the general population) [32b].
Rys. 11. Maksymalne wartości gęstości mocy i pola elektrycznego w strefie bezpiecznej (dla ogółu ludności) [32b].

However, several countries such as Switzerland, Belgium, Italy, Hungary and Poland have been using SAR, GPO and IPN values lower than those recommended by the aforementioned directives in order to take into account the prolonged effects of the exposure to weak EM fields. Some countries have introduced additional regulations. For instance, since 2014 in Belgium it has been prohibited to sell children's mobile phones and to distribute their commercials intendent for children under the age of 7. It has also become mandatory to provide the SAR values in the parameter descriptions for all mobile phones that were on the market.

8. Protection form the impact of EM fields in Poland

In Poland, as in other countries in 1960s and 1970s, extensive studies were performed on the non-thermal effects of EM radiation towards human and animal organisms. These investigations indicated the existence of non-thermal impact of EM field. Having taken the results into account, the Regulation of the Council of Ministers of 1972 adopted the limiting IPN values for a safety zone at a very low level of 0.1 W/m^2 in order to "ensure a high level of protection against the known and even yet not fully understood adverse effects of EM fields on human health." In the later Regulation of the Minister of Family, Labour and Social Policy (2016) [34] the limits for power density (IPN-p 0.1 W/m^2) and microwave fields (IPNp-E = 7 V/m, IPNp-H = 0.02 A/m^2) were maintained. These values were lower than those adopted in the Directive of the European Parliament and of the Council of 2013 (IPN-p 50 W/m^2) that has been in force till now. In January 2020. due to the projects of the 5G network installation, the Regulation of the Minister of Health [35] raised the limit values to 10 W/m^2 for power density and to 61 V/m and 9.6 A/m^2 for EM fields.

9. Conclusions

The analysis of the aforementioned Directive of the European Parliament and of the Council Leeds to the conclusion that the permissible values of EM field intensities do not protect people against the remote effects of the exposure to EM field. This situation probably derives from the fact that each attempt to lower the permissible values of radiation entails huge costs for the telecommunications companies mainly because more base stations with lower power would have to be installed. More restrictive standards will also increase the costs of the designed 5G network. Therefore these companies find that lobbing to maintain the standards, which are now in force is in their interest.

However, we should be aware of the possibility of the adverse health effects of a prolonged exposure to EM field, as demonstrated by the overwhelming number of authors. Such an impact is observed for the fields much weaker than those specified by the current standards as permissible. To make sure that the development of telecommunication is not at the expense of our health risk, further investigations, funded by the independent in-

stitutions are needed. Therefore, the task of the scientific community should be to initiate and carry out research aimed at finding out the remote effects of EM field on human organisms in order to establish its safe levels.

It should be up to the state and local authorities to control and execute consequently the measurements of the field intensity in the neighbourhood of the base stations, as the increased number of transmitters or their power and new houses built near those stations, can alter EM field distributions there. The authorities should also carry out information campaign to make people be aware of the threats due to the improper use of mobile phones and to encourage the users to take advantage of headphones or keep the phones away from the body. Such behaviour will help to reduce the risk of the adverse effects of EM radiation without additional costs.

It depends on the outcome of these actions whether the increasing EM fields, that surround us, along with nanopowders, which some scientists have started to call "asbestos of 21st century", will not become the second most serious threat of this century but will contribute to the further improvement of the quality of our lifes.

References

[1] Sarlandière J.B.: Memoires sur l'electropuncture - traite sur l'electroacupuncture, Paris 1825.

[2] Duchenne G.B.: A treatise on localized electrisation, and its applications to pathology and therapeutics, *Lindsay & Blakiston*, London 1871.

[3] D'Arsonval J.A.: Action physiologique de courants alternatifs a grand frequence, *Arch. Physiol. Normale et Oatologique*, vol. 5, no. 401-408, pp. 780-790, 1893.

[4] Rafai A.B., Hakami M.A.: Health Hazards of Electromagnetic Radiation, *Journal of Biosciences and Medicines*, vol. 2, pp. 1-12, 2014.

[5] Kubacki R.: Impact of electromagnetic fields on organisms (in Polish, *Oddziaływanie pól elektromagnetycznych na organizmy*), KEiT PAN Report, Warszawa 2008.

[6] Jeleński A., Kubacki R.: Electromagnetic radiation: threats and safety limits (in Polish, *Promieniowanie elektromagnetyczne: zagrożenia i granice bezpieczeństwa*), report in "Poland 2000 Plus" Foresight Committee, Polish Academy of Sciences, PAN. Warszawa 25.06.2014.

[7] Sierck P.: Scientific Study: RF Radiation Levels From Cellular Towers, *EMF & RF Solutions Information and News*, January 27, 2015.

[8] Karpowicz J., Gryz K.: An assessment of hazards caused by electromagnetic interaction on humans present near short-waves physiotherapeutic devices of various types including hazards for users of electronic active implantable medical devices (AIMD), *Biomed. Res Int.*, Article ID 150143, 2013.

[9] Bozic I.: Elektromagneta poljain valovanja (sevanja) na delovnih mestih. http://www.zbornica-vzd.si/media/3_EMS_osnutek uredbe_Bo%C5%Bei%C4%8D.pdf.

[10] Gandhi O.P., Lazzi G., Furse C.M.: Electromagnetic Absorption in the Human Head and Neck for Mobile Telephones at 835 and 1900 MHz, *IEEE Trans on Microwave Theory and Techniques*, vol. 44, no. 10, pp. 1884-1895, 1996.

[11] Ahlbom A., Day N., Feychting M., et al.: A pooled analysis of magnetic fields and childhood leukaemia, *Br J Cancer.*, vol. 83, no. 5, pp. 692-698, 2000.

[12] Feychting M., Alhbom M.: Magnetic fields and cancer in children residing near Swedish high-voltage power lines, *American Journal of Epidemiology*, vol. 138, no.7, pp. 467-481, 1993.

[13] Draper G1., Vincent T., Kroll M.E., Swanson J.: Childhood cancer in relation to distance from high voltage power lines in England and Wales: a case--control study. *The BMJ*, vol. 330, no. 7503, pp. 1290 -1293, 2005.

[14] Feychting M., Jonsson F., Pedersen N.L., Ahlbom A.: Occupational magnetic field exposure and neurodegenerative disease, *Epidemiology*, vol.14, no. 4, pp. 413-419, discussion 427-428, 2003.

[15] Kanai R., Chaieb L., Walsh V., Oaulus W.: Frequency dependent electrical stimulation of the visual cortex, *Current Biology*, vol. 18, pp. 1839-1843, 2008.

[16] BioInitiative Report 2012. www.bioinitiative.org.

[17] Grigoriev Y., Electromagnetic Fields and the Public: EMF Standards and Estimation of Risk, *IOP Conf. Ser.: Earth Environ. Sci.*, vol. 10, 012003, 2010.

[18] Frey A.H.: Biological function as influenced by low power modulated RF energy, *IEEE Transactions on Microwave Theory and Techniques*, MTT, vol. 19, no. 2, pp. 153-164, 1971.

[19] Frey A.H., Messenger R. Jr.,: Human Perception of Illumination with Pulsed-modulated Ultrahigh-Frequency Electromagnetic Energy, *Science*, Vol. 181, issue 4097, pp. 356-358, 1973.

[20] Elder J.A, Chou C.K.: Auditory response to pulsed radiofrequency energy. *Bioelectromagnetics*, Suppl. 6, pp. 162-173, 2003.

[21] Batoli S., et al., Benefits and hazards electromagnetic waves telecommunication physical and biomedical, *European Review for Medical and Pharmacological Sciences*, vol. 23, pp. 3121-3128, 2019.

[22] Salford, L.G., Nittby H., Brun A., et al. The Mammalian Brain in the Electromagnetic Fields Designed by Man with Special Reference to Blood-Brain Barrier Function, Neuronal Damage and Possible Physical Mechanisms, *Progress of Theoretical Physics Sup-*

plements, vol. 173, pp. 283–309, 2008.

[23] Sirav B., Seyhan N.: Blood-Brain Barrier Disruption by Continuous Wave Radio Frequency, *Radiation. Electromagnetic Biology and Medicine*, vol 29, no. 2, pp. 215-222, 2009.

[24] Nittby H., Brun A., et all. Increased blood–brain barrier permeability in mammalian brain 7 days after exposure to the radiation from a GSM-900 mobile phone, *Pathophysiology*, vol. 16, no. 2–3, pp. 103–112, 2009.

[25a] Hardell L.O., Carlberg M., et al.: Long-term use of cellular phones and brain tumours - increased risk associated with use for > 10 years, *Occupational Environmental Medicine*, vol. 64, no. 9, pp. 626-632, 2007.

[25b] Hardell L., Carlberg M., et all.: Meta-analysis of long-term mobile phone use and the association with brain tumours, *Int. J. Oncol.*, vol. 32, no. 5, pp. 1097-1103, 2008.

[25c] Hardell L., Carlberg M., Mobile phones, cordless phones and the risk of brain tumours, *International Journal of Oncology*, vol. 35, no. 1, pp. 5-17, 2009.

[25d] Hardell L., Carlberg M., Increasing rates of brain tumours in the Swedish national inpatient register and the causes of death register, *Int. J. Environ. Res. Public Health.*, vol.12, no. 4, pp. 3793–3813, 2015.

[26] Pareja-Peña F et al., Evidences of the (400 MHz – 3 GHz) radiofrequency electromagnetic field influence on brain tumour induction, Published online: 09 Mar 2020.

[27a] Hocking B., Gordon I.R., et all. Cancer incidence and mortality and proximity to TV towers, *Med J Aust.*, vol. 165, no. 11-12, pp. 601-605, 1996. Erratum in: *Med J Aust.*, vol. 166, no. 2, 1997.

[27b] Hocking B., Gordon I., Hatfield G.: TV towers and childhood leukemia, *Australian and New Zealand Journal of Public Health*, vol. 24, no. 2, pp. 216–217, 2000.

[28] Batoli S. et al.: Benefits and hazards of electromagnetic waves. telecommunication, physical and biomedical., *S. European Review for Medical and Pharmacological Sciences*, vol. 23, pp. 3121-3128, 2019.

[29] SSM's Scientific Council on Electromagnetic Fields. Recent Research on EMF and Health Risk, Thirteenth report from SSM's Scientific Council on Electromagnetic Fields, SSM, pp. 1-104, 2019.

[30] Health Effects from Radiofrequency Electromagnetic Fields. Report of an independent Advisory Group on Non-ionising Radiation, Documents of the NRPB, vol. 14, no. 2, 2003.

[31a] International Agency for Research and Cancer. IARC Classifies Radiofrequency Electromagnetic Fields as Possibly Carcinogenic to Humans, Press Release, no. 208, 31 May 2011.

[31b] International Agency for Research and Cancer. IARC Monographs on the Evaluation Carcinogenic Risk to Human, IARC Publications, vol. 102, 2013.

[32a] ICNIRP Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic Fields [1 Hz to 100GHz], *Health Physics*, vol. 99, pp. 818 -836, 2010.

[32b] INCIRP Radiofrequency Guidelines 2020, https://www.icnirp.org/en/activities/news/news-article/rf-guidelines-2020-published.html.

[33] Directive of the European Parliament and the EU Council. 2013/35/UE, Official Journal of the European Union, 26 June 2013, L179/1.

[34] Regulation of the Minister of Family, Labour and Social Policy of 27 June 2016 amending the regulation on maximum permissible concentration and intensity of agents harmful to health in the working environment, Journal of Laws R.P. [Dz. U.] 30.06.2016, Item 952.

[35] Regulation of the Minister of Health of 17 December 2019 on permissible levels of electromagnetic fields in the environment, Journal of Laws R.P. [Dz. U.], 19/12.2019, Item 2448.