Radiation standards review concerning non-ionizing radiation

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ABSTRACT

This article discusses the aspects related to the use of modern technologies based on electromagnetic non-ionizing radiation, such as the 5G network. Current normative values for safe levels of non-ionizing radiation in Poland, Europe and the United States were presented. The selected 5G network issues have been discussed with the example of acceptable values of non-ionizing radiation and current regulations in Poland were briefly presented. All types of non-ionizing radiation and the risk of contact with each of them were also discussed.

Keywords: electromagnetic radiation, non-ionizing radiation, 5G network, security of modern technologies

1. INTRODUCTION

The electromagnetic field is a form of energy emitted by charged particles. During moving through the space it behaves like a wave with oscillating electric and magnetic components which are perpendicular to each other and to the direction of movement[8, 9, 24]. The waves are in phase. The beginning of existence of electromagnetic wave is a charged particle that creates an electric field. When the particle accelerates and oscillates it creates waves or oscillation in the electric filed and eventually creates magnetic field. Time-variably electric field creates magnetic field and time-variably magnetic field creates electric field - according to Maxwell's equations[3, 4].

There are two types of electromagnetic radiation: ionizing radiation and non-ionizing radiation. Non-ionizing radiation is the radiation in which the radiation energy is too low to trigger the ionization process in the medium thorough which it passes, i.e. to trigger the emission of an electron from an atom or a molecule. Only high-frequency radiation has ionizing properties, i.e. ultraviolet radiation, X-radiation and gamma radiation for which lengths of waves are comparable with the sizes of atoms and molecules[8, 9, 23]. Electromagnetic radiation spectrum range is presented in Figure 1.

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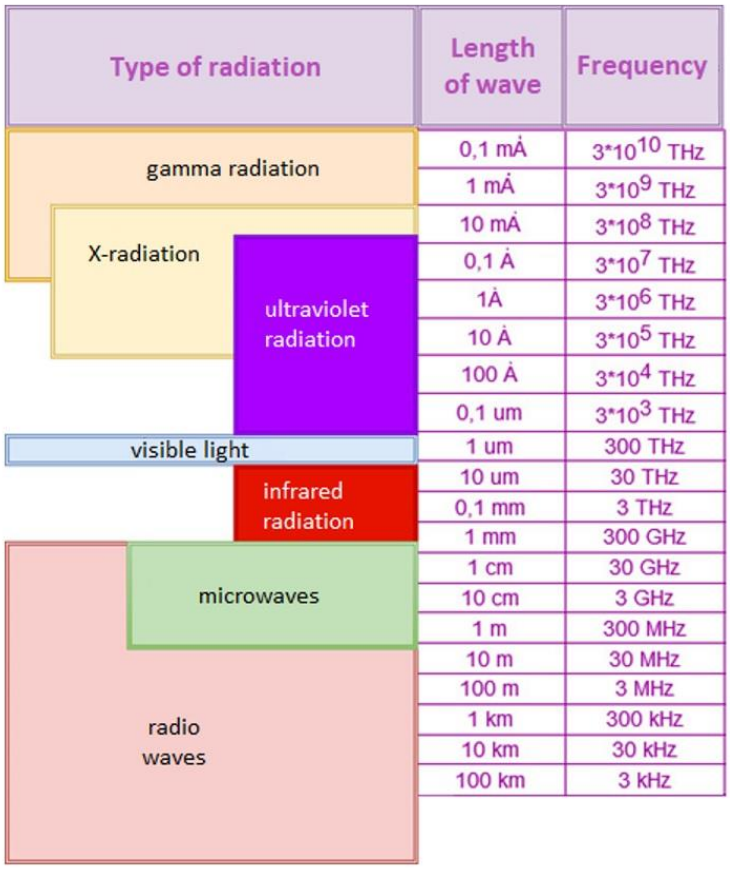

Figure 1. Electromagnetic waves spectrum[8].

There are two types of radiation in the environment: natural radiation that is not associated with human activity and all organisms have adapted to it in the process of evolution, and artificial sources of radiation associated with the access to the electromagnetic energy. Natural sources of radiation include, among others: thermal radiation of bodies on Earth, solar radiation, natural changes in the Earth's magnetic field, natural changes in the electric field, e.g. atmospheric discharges and radio waves of extraterrestrial origin, not absorbed by the atmosphere. Artificial radiation sources include mainly high-voltage overhead power lines, radio and television stations, radio communication (CB radio, radiotelephones and mobile network), radiolocation and radio navigation stations, transformer stations, household appliances, and electrical installations[8].

Nowadays, electromagnetic radiation is an indispensable element of human life environment. The widespread use of various types of electrical devices and their increasing number, as well as the dynamic development of modern telecommunications technologies made it necessary to control the levels of electromagnetic field intensities in the environment, both in everyday life and in the workplace, and to protect the population from the effects of excessive influence of these fields[5].

2. NON-IONIZING RADIATION STANDARDS

According to numerous studies and experiments carried out, the electromagnetic field does not affect the functioning of living organisms, provided that certain established acceptable standards are not exceeded. It is therefore necessary to standardise the impact of the electromagnetic field, which consists in establishing maximum permissible levels in order to limit the impact on living organisms and to minimise any adverse effects that may occur. To this end, all the latest scientific reports on the subject are being analysed[6], with the most important role played by the World Health Organization (WHO) programme launched in 1996, entitled Electromagnetic Fields[7], and the recommendations of the International Commission on Non-Ionizing Radiation Protection (ICNIRP)[10, 11].

2.1 Polish standards

Poland is one of the few countries which has a comprehensive legal system protecting citizens and the environment against electromagnetic non-ionizing radiation[8]. The most important document regarding electromagnetic radiation in the environment in Poland is the Regulation of the Minister of the Environment of 30 October 2003 (Journal of Laws No. 192, item 1883) on permissible levels of electromagnetic fields in the environment and methods of verifying compliance with the levels of these fields[1], pursuant to Article 122 of the Act of 27 April 2001 – Environmental Protection Law (Journal of Laws No. 62, item 627, as amended)[2], the Regulation specifies:

- permissible levels of electromagnetic fields in the environment;
- frequency ranges of electromagnetic fields for which physical parameters characterising the environmental effects of electromagnetic fields are specified;
- methods for verifying compliance with the permissible levels of electromagnetic fields;
- methods of determining compliance with the permissible levels of electromagnetic fields.

Limits concerning electromagnetic field in Poland are among the highest in Europe and are much stricter than those recommended by the WHO and ICNIRP[6, 10]. The existing differences result from historical and political considerations. Higher limits were arbitrarily established and adopted in socialist countries. The tightening of standards was aimed at restricting citizens' access to wireless communications. The permissible values of parameters characteristic for the impact of the electromagnetic field are presented in Table 1 and Table 2.

Table 1. Permissible values of electromagnetic field parameters for areas intended for residential buildings[7].

Electromagnetic field frequency range	**Electric component**	**Magnetic component**	**Power density**
50 *Hz*	1 *kV/m*	*60 A/m*	-

Table 2. Permissible values of electromagnetic field parameters for areas accessible for the public[1, 7].

Electromagnetic field frequency range	**Electric component**	**Magnetic component**	**Directional energy flux**
0 *Hz*	10 *kV/m*	2500 *A/m*	-
From 0 *Hz* to 0,5 *Hz*	-	2500 *A/m*	-
From 0,5 *Hz* to 50 *Hz*	10 *kV/m*	60 *A/m*	-
From 0,05 *kHz* to 1,0 *kHz*	-	3/*f A/m*	-
From 0,001 *MHz* to 3,0 *MHz*	20 *V/m*	3 *A/m*	-
From 3,0 *MHz* to 300 MHz	7 *V/m*	-	-
From 300 *MHz* to 300 *GHz*	7 *V/m*	-	0,1 W/m^2

The directional energy flux is determined on the basis of the Poynting vector, named after the discoverer John Henry Poynting[24]. The vector is defined as the vector product of the electric and magnetic field strength vectors:

$$\boldsymbol{S} = \boldsymbol{E} \times \boldsymbol{H} \tag{1}$$

S – Poynting vector, W/m^2.

Due to the dependence between magnetic flux density *B* and magnetic field strength *H*, the formula can be transformed into:

$$\boldsymbol{S} = \frac{1}{\mu}\boldsymbol{E} \times \boldsymbol{B} \quad (2)$$

μ – material dependent magnetic permeability , H/m.

2.2 European standards

In 1999, the Council of the European Union published the recommendation on limiting public exposure to the effects of electromagnetic fields (0 Hz to 300 GHz) (1999/519 / EC). The recommendation was created based on guidelines regarding limiting of exposure to electric, magnetic and electromagnetic fields changeable over time (up to 300 GHz) of the International Commission on Non-Ionizing Radiation Protection (ICNIRP)[11, 12].

According to the EU recommendation, the permissible values for high voltage lines, i.e. 50 Hz, are respectively:

- **electric field strength 5 *kV/m,***
- **magnetic flux density 100 μT.**

In the European Union, there is no established uniform legal obligation for all countries of the Community to apply the same standards, so Member States apply the 'recommendation' on the permissible values in different ways. 3 groups of countries are distinguished[12]:

1. Countries that have implemented the Recommendation's standards as national regulations. These include:

- Estonia,
- Greece,
- Malta,
- Austria,
- Portugal,
- Romania,
- Slovakia,
- Czech Republic,
- Hungary,
- Cyprus.

Some countries have implemented additional restrictions, such as the possibility of short-term exceedances in Belgium and Finland. Additional restrictions have also been applied by:

- Germany,
- France,
- Croatia,
- Luxembourg.

2. Countries that have not implemented the EU Recommendation in their legislation. These countries include:

- the United Kingdom, where the limits are higher;
- Bulgaria, Sweden and Spain, where limits are not set but other restrictions exist, e.g. on the distance between high-voltage lines and buildings;
- Latvia and Ireland, where there are no established rules on the subject.

3. Countries from a third group, which includes, among others: **Poland**, where the regulations are stricter than the requirements of the EU recommendation. They are based on the precautionary principle or were introduced due to public pressure. Apart from **Poland**, the following countries also belong to the third group:

- Denmark,
- Italy,
- Lichtenstein,
- Lithuania,
- the Netherlands,
- Switzerland,
- Slovenia.

2.3 Standards in the United Stations

In the United States, legal regulations concerning protection against the potential effects of non-ionizing radiation are similar to those in force in Western European countries and are based on IEEE (Institute of Electrical and Electronic Engineers) and ICNIRP recommendations[10, 12, 13]. According to the standard published by the Federal Communications Commission (FCC), the exposure limit for 2000 *MHz* electromagnetic fields (used by many mobile operators worldwide) is 10 W/m^2 [14].

The regulations for individual states may vary slightly and impose more specific restrictions. For example, in California[15], detailed recommendations for different values of electromagnetic field frequencies (microwave radiation, radio waves, very low frequency radiation) are set out in the California Code of Regulations (CCR, 8, section 5085, subsection 7, group 14, Article 104 – Non-ionizing radiation), which sets maximum limits, including workplace exposure limits, that are binding on all employers in California.

Moreover, limit values for ultra-wideband emissions have been set in accordance with regulations[28].

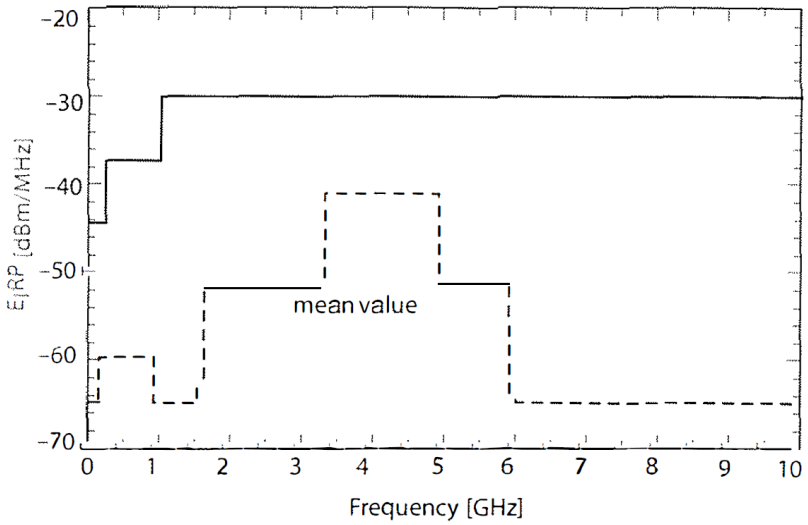

Figure 2 Limits for power spectral density for ultra-wideband signals[28].

3. 5G NETWORK AND NON-IONIZING RADIATION

5G network is the latest standard in mobile telephony – a fifth generation network that will slowly replace and substitute 4G/LTE network. 5G network is to offer customers much better performance and reliability, its specification published by the International Telecommunications Union is as follows[16]:

- transfer rate – download up to 20 *Gb/s* and upload up to 10 *Gb/s*;
- delay – up to 4 *ms*, but up to 1 *ms* possible;
- load – up to 1 million devices per 1 km^2;
- reliability – maintaining connection while on the move at speeds up to 500 *km/h*.

The 5G technology will use the frequency bands already used in the 4G network, i.e. from 700 to 2600 *MHz*, and new frequency bands will be added[16]:

- **L Band** – 300 *MHz* frequency, which will allow to increase the range;
- **Sub-6** – a frequency between 3000 and 6000 *MHz*, which is a compromise between speed and range;
- **mmWave** – meaning millimetre waves – from 17,000 *MHz* to tens of thousands of *MHz*, guaranteeing super-speed on short distances.

The new 5G technology, despite many advantages, also arouses fear in the society. There are numerous articles and short videos on the Internet e.g. on YouTube, warning about the harmfulness of radiation associated with the fifth generation network. In autumn 2018, the city of Gliwice in Poland even organized a protest against testing this new technology[17]. The 5G network requires a higher density of telecommunication masts, which is connected with the concentration of electromagnetic radiation. Therefore, it may be necessary to increase the limits from the restrictive Polish standards to the level recognized as safe by the World Health Organization. Mobile telephony operators in Poland have been taking steps in this direction for many years, and the Ministry of Digitization is also proposing changes to the existing law[18].

4. DANGERS RELATED TO NON-IONIZING RADIATION AND SAFETY RULES

Ionizing radiation, as opposed to non-ionizing radiation, can penetrate deep into human tissues and cause permanent and very dangerous changes in the human body, such as burns, acute radiation syndrome, cancer, and genetic damage. However, exposure to non-ionizing radiation is also not completely indifferent to our health. Its effects may be different and strictly dependent on factors such as:

- exposure time,
- radiation intensity,
- frequency, or the type of radiation.

Non-ionizing radiation may cause local heating or photochemical reactions with the possibility of causing permanent damage. It is necessary to minimize exposure and take appropriate protective measures depending on the type of radiation, among which the following are distinguished: optical radiation, microwave radiation and radiation of low and very low frequency[19].

4.1 Optical radiation (from 100 *nm* to 1 *mm*) – ultraviolet radiation, visible light, infrared radiation

Optical radiation is characterized by low wavelength, high frequency and high energy. Thermal and photochemical effects are possible. Radiation easily interacts with surfaces and can be accumulated in human tissues[15]. The main sources of this type of radiation, which can be encountered on a daily basis, include:

- Lamps (incandescent, discharge, fluorescent, arc, semiconductor lamps, etc.);
- Plasma sources (welding equipment, etc.);
- Heat sources (furnaces, molten glass, open fire, etc.).

Such radiation sources should be shielded to prevent exposure of eyes or skin. Another solution is also the filtration of dangerous wavelengths.

Ultraviolet radiation is a known carcinogen for human skin. Excessive exposure to UV radiation can also cause sunburn and faster skin ageing. Excessive eye exposure also has serious consequences. As a result of photochemical reactions, different parts of the eye can be damaged depending on the frequency of radiation. Particularly sensitive is the cornea, whose 'burn' can cause painful corneal inflammation, and in extreme cases even the opacification shown in Figure 3, which means loss of sight[15, 19].

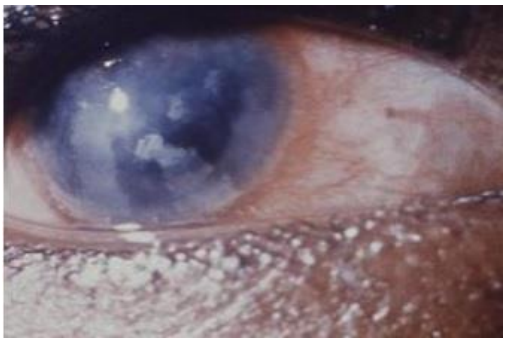

Figure 3. Corneal opacification, which may occur as a result of exposure to optical radiation[25].

In the case of visible light, aversion due to too bright light (blinking, turning the head away) is a natural defence reaction of the body. The desire to overcome this natural defence mechanism of the body and forcing oneself to look at light can cause permanent damage to the retina and loss of sight. Light sources that are not so bright as to damage the retina are not completely safe for human eyes – they can also cause deterioration in colour vision and vision after dark. Especially harmful is blue light (corresponding to a wavelength of 400-500 *nm*), which can cause similar injuries as UV radiation.

Depending on the type, infrared radiation poses different risks to human health. Shorter wavelength radiation focuses on the delicate retina, while longer wavelengths can cause burns to the cornea, skin and the lens of the eye, resulting in a cataract.

4.2 Microwave radiation (from 300 *MHz* to 30 *GHz*)

Microwave radiation is characterized by moderate wavelengths from 1 *mm* to 1 *m* and moderate photon energy. It is a type of radiation that resonates, i.e. creates standing waves in tissues with a multitude of ½ wavelength (depending on the orientation of the tissue and the wavelength plane)[14]. Sources of microwave radiation in the human environment can be divided into three basic groups:

- sources designed to emit radiation into the environment – mainly radio and television antennas;
- sources designed to produce or safely limit microwave radiation but which may present a hazard, such as cables, waveguides, transmission generators, cookers, heaters;
- sources that produce microwave radiation as a side effect of their operation, e.g. power supplies.

The hazards associated with this type of radiation and the ways in which it is reduced are closely linked to the radiation parameters – frequency, power density, near or far field exposure and the orientation of the human body in the field of radiation.

The influence of microwave radiation on the body includes both the thermal effect, i.e. direct heating of tissues, as well as effects resulting from the flow of induced current through the human body. Radiation heating is most dangerous for the brain, eyes, genitals, stomach, liver and kidneys, and can cause cataracts, inductive burns and burns caused by contact with metal elements: implants, glasses, etc. Non-thermal effects causing cancer are also observed in animals, but none of the studies conducted have shown such effects in humans[15, 19].

4.3 Low-frequency radiation (from 300 *Hz* to 10 *MHz*) , very low-frequency ELF radiation (from 0 *Hz* to 300 *Hz*) and static fields

A magnetic field is induced during the current flow through the cable. Such fields with a frequency close to the frequency of the current flowing through the conductor are called Extremely Low Frequency (ELF) fields. Static fields are basically natural fields, such as Earth's magnetic field, or fields produced by friction[19]. The ELF radiation spectrum is shown in Figure 4.

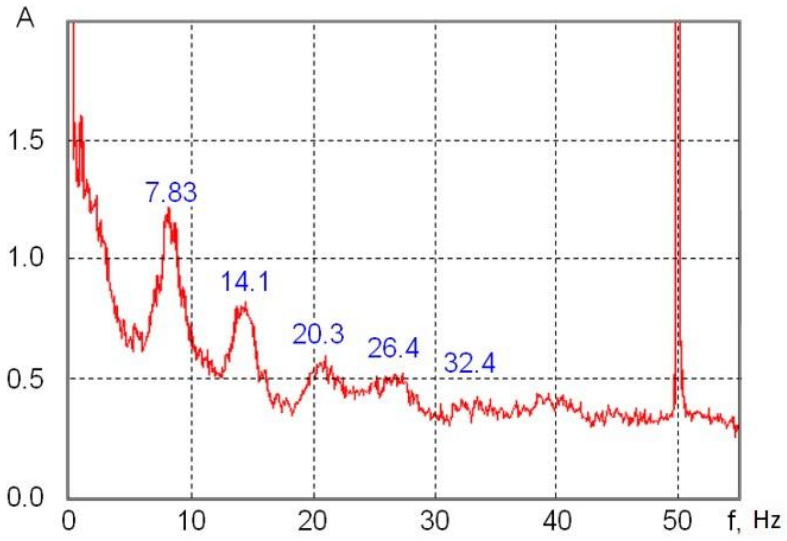

Figure 4. Spectrum of electromagnetic waves ELF in the Earth's atmosphere with visible peaks occurring due to Schumann's resonance f = 7.83 Hz (frequency at which the wavelength is equal to the circumference of the Earth), higher harmonics of Schumann's resonance frequencies induced by lightning strikes and due to the influence of power networks (f = 50 Hz)[27].

Very low-frequency radiation is characterized by significant wavelengths, over 1 *m* and low energy. The impact of radiation energy on human tissues is weak but observable, both in terms of thermal effects and the induction of currents. Radiation easily penetrates into the human body, but rarely accumulates in tissues[15].

Numerous studies have been carried out, but none have shown that static fields and extremely low frequency fields have a clear impact on human health and life. The greatest hazard is the risk of electric shock from touching an object. Static magnetic fields cause small differences in electrical potentials in blood vessels, but the consequences for humans are not known.

Low-frequency variable fields generate electric currents in the human body that can directly activate nerves and muscles. However, no permanent and harmful effects of their flow are known. Short-term exposure to this type of radiation may adversely affect some artificial elements designed to make people's lives easier, such as pacemakers and ferromagnetic implants, which may cause a direct threat to life or health[18].

5. SUMMARY

The development of new technologies is inevitable. People encounter them almost every day. Development has always been controversial and has caused extreme emotions. In every field of science there are enthusiasts fascinated by every technological innovation, as well as zealous opponents who consider every change unnecessary and harmful to the environment and society.

From the very beginning of its existence, mobile telephony has been treated by many as a potential source of danger to our health, in the form of an increase in the incidence of certain types of cancer or infertility, as a result of exposure to electromagnetic radiation. As for technologies using non-ionizing radiation, and in particular the widely commented fifth generation network recently, the harmful effects of radiation on human health have not been clearly demonstrated. However, scientists do not have reports that would definitely deny this. For many years, numerous tests and studies have been carried out, resulting in sometimes contradictory and mutually excluding results, which only fuel negative moods in the society.

Poland, as a former Eastern Bloc country, has maintained stricter standards in its legislation concerning the permissible level of non-ionizing radiation, which, at present, should give a sense of relative security even to sceptics when it comes to new technologies in the field of telecommunications. Restrictive limits are a significant obstacle to the introduction of fast 5G Internet in Poland. According to the European Commission's findings, Poland, like other member states, must launch 5G networks in first big city in 2022. Three years from then, the fifth generation network should already operate

in larger cities and on major transport routes[21]. The first steps taken by the Polish mobile operators and the Government to this end are already visible. This is evidenced by the amendment to the Act on supporting the development of telecommunications services and networks[22] adopted in July 2019. Owing to the new regulations, the investment and construction process related to, among others, the construction of broadband networks will be shorter and simpler.

Regardless of the favour of the government, the 5G network is still a matter of great controversy and opposition in our country, as evidenced by the loud protests and demonstrations. In the case of introducing any new technology, awareness-raising social campaigns should be prepared in consultation with specialists from the scientific world. Every citizen should be aware of all the advantages and disadvantages of the new solution.

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