Radiofrequencies and health : where are we ?

Mobile telephony and new wireless communication technologies have developed exponentially since the 1990s. At the same time, fears have arisen about the possible harmful effects of electromagnetic waves such as radio frequencies on health. We hear everything and its opposite on this subject. For health agencies, the use of these waves is the subject of attention, but does not seem to pose a problem insofar as their use is regulated. They rely on collective expert reports that analyze in detail the available scientific literature to assess the risk. The regulations are based on scientific evidence. However, a number of press articles, radio and television broadcasts, videos and websites regularly report on the dangers. Radio frequencies are said to be carcinogenic, dangerous for children, for fertility, for immunity, etc. The 5G would be a new threat. Testimonies of so-called "electrosensitive" or "electrohypersensitive" (EHS) people are relayed. What exactly is the situation? What are the risks? How are they assessed and regulated? This article offers an overview of the subject based on the case of mobile telephony.

1. The waves that surround us: what are they?

We live within magnetic and electromagnetic fields of **multiple origins, natural and artificial**. Light, ultraviolet (UV) and infrared (IR) radiation emitted by the sun, and the earth's magnetic field are determining factors for life on earth. Light, infrared and UV can also be produced artificially. For example, all warm bodies emit IR radiation, whether they are living beings, a radiator in a room, a stone heated by the sun... The sources of radiation have diversified with the establishment of the electrical distribution network. **New low-frequency electric and magnetic fields** (50 Hz, 60 Hz and their harmonics) then appeared in the environment, followed by **radio frequencies**, only a very small proportion of which are of natural origin and come from the cosmos [1]. For more than a hundred years, it has been known that all these radiations are associated with a wide range of physical phenomena and effects that differ according to the characteristics of the radiation considered. They are used for a wide range of applications, not only in everyday life, but also for medical, industrial and military purposes (Figure 1).

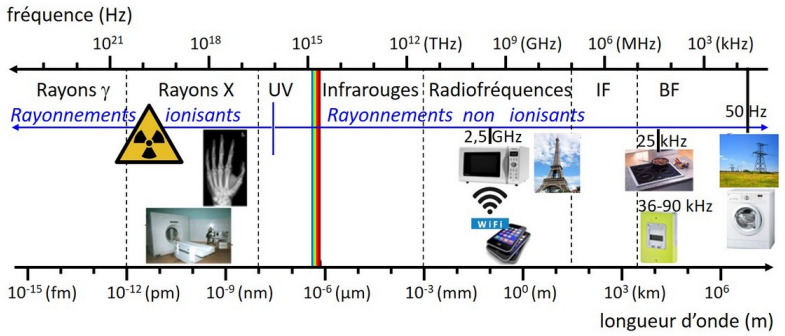

Figure 1. Simplified diagram of the frequency range and examples of applications. UV: ultraviolet; IF: intermediate frequencies; LF: low frequencies; Kilohertz: 10^3 Hz; Mega: 10^6; Giga: 10^9) [Source: Perrin & Souques, © EDP-Sciences, 2018]

Wave physics is based on corpuscular (quantum mechanics) and wave (Maxwell's equations) models, which are complementary and compatible. According to the corpuscular model, waves carry particles of varying energies depending on the frequency (energy of photons). A distinction is made between ionizing radiation (X-rays, alpha and beta gamma rays, some UV rays), which can tear electrons from atoms and cause DNA breakage, and **non-ionizing radiation** at lower frequencies, below the UV level (see The cellular impact of solar UV).

Interactions with living organisms differ according to the frequency. Up to 100 kHz, fields and currents can stimulate excitable tissues (nervous systems and muscles). Above 10 MHz, absorption by the tissues becomes predominant and heating the essential mechanism. At the so-called intermediate frequencies, between 100 kHz and 10 MHz, there is a mixture of both (Figure 2).

Figure 2. Warning pictogram for non-ionizing radiation [Source: royalty-free / Pixabay]

In this article, we are interested in non-ionizing radiation of the **radio frequency** type that is used for the most common **wireless communications**, located above 10 MHz (which will be referred to as radio frequency). For the physical and technical aspects, please refer to the focus "**Radiofrequency and Wireless Communications"** and to reflect on the notion of risk and understand the regulations, to the focus on "**Radiofrequencies risk and regulation**".

1.1. What happens when radio waves reach the body?

Waves are both reflected by the body (about 50% reflection around GHz) and absorbed within biological tissue. The depth of penetration and the effects of electromagnetic waves differ according to the frequency. This absorption depends on many parameters: temperature, physico-chemical characteristics of the material (permittivity, conductivity, density), exposure level

(incident power), type of signal, etc.

In the radio frequency range

The higher the frequency, the less the waves penetrate the body, their absorption is limited to the skin from about 6 GHz. The quantities that account for exposure at body level are therefore not the same. **Below 6 GHz**, the penetration depth can reach several centimetres. The **specific absorption rate (SAR)** is the quantity that represents the **amount of energy absorbed per unit of mass (in watts per kilogram, W/kg).** Since the penetration of waves varies with frequency, the amount of energy absorbed, and therefore the resulting SAR, also varies with frequency for the same incident power. The SAR value is obtained by biological dosimetry using physical measurements and numerical simulation methods. The maximum absorption is around 80 MHz for the human body. **Above 6 GHz**, the absorption of the waves is increasingly superficial at the skin level. The exposure indicator is the **absorbed power density (S_{ab}) in watts per square meter (W/m^2) for localized exposures**. However, sufficiently intense surface exposures over the whole body could eventually lead to deeper heating. SAR therefore also remains an indicator for the whole body (a consideration introduced in the latest ICNIRP recommendations in 2020, see focus **Radiofrequencies, risk and regulation**).

1.2 Thermal effects of radio frequencies and critical thresholds

It has been known for a long time that the interaction of RF with matter leads to **heating**, mainly due to the agitation of water molecules. The higher the water content, the greater the temperature increase. This is known as a **threshold effect** because this phenomenon occurs after a certain amount of energy has been absorbed, i.e. after a certain level of exposure. This effect is used in many applications: microwave ovens, surgery, industrial thermobonding for example (tarpaulins, blinds...). **Mammals** have a temperature regulation system that can cope with variations of a few degrees Celsius. Heat is eliminated largely through the vascularization of tissues by normal physiological processes of thermoregulation. A potentially harmful thermal effect occurs when this **adaptive capacity is exceeded**, starting at critical thresholds. The first effects observed are behavioural disorders in fully exposed primates, and for localised exposures, burns and cataracts, as the eye has very little vascularisation. The critical SAR values derived from scientific data (animal experiments) are:

- 4 W/kg for "whole body" exposure

- 100 W/kg for localized exposure (on average on 10 g of tissue)

For wireless communications, the exposure levels are **low** enough not to induce heating due to the waves (see focus Some preconceived ideas). There are regulations that set exposure limits that must not be exceeded to protect the population (Read focus **Radiofrequencies Risk and Regulation**). To study the effects of radio waves in the laboratory, the nuance "near field" / "far field" is important to define the conditions and the exposure system to be used according to the objective of the study (whole body or localized exposure).

2. From research to risk assessment - state of knowledge

2.1. Why conduct research if the effects are known?

Since the 1980s, research has focused on the possible **non-thermal effects** of radio frequencies. These are effects that are not caused by a change in temperature and occur at low levels of exposure, below critical thresholds. Fears about possible harmful effects of mobile phones were expressed as early as 1993 with a well-publicised trial in the USA. A manufacturer was accused of being responsible for the death of a woman suffering from a brain tumour [2]. On the other hand, for more than 20 years, the installation of telephone antennas has led to debates in which risks for the health of local residents are often put forward [3].

Mobile phones are the main source of exposure to radiofrequencies for the population, due to their positioning close to the head or body during communications, and their widespread use. The SARs generated are well **below the critical thresholds**, but mobile phones have introduced a new exposure situation (see focus **Radiofrequencies risks and regulations**). Instantaneous exposure to the phone is tens of thousands of times higher than that generated by antennas, in terms of SAR.

Given the popularity of this technology, the hypothesis of a health risk, even if small, has been taken seriously. For these reasons, most of the studies concern exposure to mobile telephony in the frequency bands concerned. This work allows for a regular assessment of the risk and the relevance of regulatory thresholds. As technologies are constantly evolving, the resulting **conditions of exposure** of individuals are also evolving. This may give rise to new questions, rumours or opposition, as is currently the case with the arrival of 5G.

2.2. Why are the methods used in research so controversial?

Type d'études	Nombre de publications
Expérimentales (biologiques, médicales)	1 341
Epidémiologiques*	311
Autres revues (dosimétrie, techniques, réglementation, interférences, articles non classés...)	2 864
Sociologie, psychologie (communication sur le risque, perception, enquêtes...)	100
Total	4 616

** Dont 116 portant sur la recherche d'associations entre exposition aux radiofréquences et tumeurs cérébrales*

Table 1. Studies on the biological and health effects of radio frequencies used by wireless communication systems. [Source: © EMF Portal]

Numerous studies have been conducted on cultured cells, animal models and humans. The aim is to examine whether biological and physiological effects or diseases can be induced, modified or aggravated by radio waves. Experiments have also been carried out on animals exposed to radio frequency radiation on a one-off basis or throughout their lives, including from the gestation period. Table 1 summarizes the number of studies on the biological and health effects of radio frequencies used in wireless communications, including studies in the humanities and social sciences.

In the laboratory

As with other toxicological studies, the experiments are designed to compare what happens in the presence (or absence) of the risk factor of interest, in this case RF.

It is **essential to know the SAR value** in the frequency bands concerned, or the incident power absorbed at the surface at higher frequencies. Controlling the exposure characteristics, including SAR, is the main difficulty in these studies. This is more complicated than in "classical" toxicology, where researchers test different doses of a substance (quantified in grams administered per kilogram, for example). Waves cannot be weighed... The **exposure system must be adapted and sized** [4]. For example, placing a telephone on a rat, on a box containing sperm or on eggs, placing animals in front of a microwave oven with a broken door or a television, as has already been done, are among the most crude errors. The presence of the waves should be the only parameter that differs between samples, animals, or exposed volunteers and controls. Unexposed controls (called "*shams*") should therefore be placed under identical conditions but with the transmitter turned off. The **specific biases** in this field of research are difficult to spot when reading a scientific article because it requires expertise in physics, biology and bioelectromagnetism.

In the population

Epidemiological studies aim to find a link between disease and exposure. There are two types of epidemiological studies. **Case-control** studies, in which people suffering from a disease whose cause is being investigated are included. Exposure assessment is generally based on the participants' memories. *Recall* bias can distort the results, particularly in remote situations or when the respondents are relatives of sick or dead people. Conversely, **cohort** studies aim to compare the evolution of pathologies or the health of individuals over time, in more or less exposed populations. Here again, the evaluation of the actual exposure of subjects to radiofrequency waves is delicate because it also depends on the chosen indicator (duration of communication, positioning of the telephone, telephone subscriptions, etc.). Environmental parameters related to lifestyles or specific to individuals may play a role in health status (confounding factors) and must also be taken into account [5].

Interpreting the results of population-based studies is complicated. In general, these studies **do not identify small-scale effects** in certain subgroups. For wave effects, collaboration with physicists specialised in biological dosimetry can be useful to best assess exposure levels and the larger the sample size, the more conclusive the study result will be.

Has there been much research in this area?

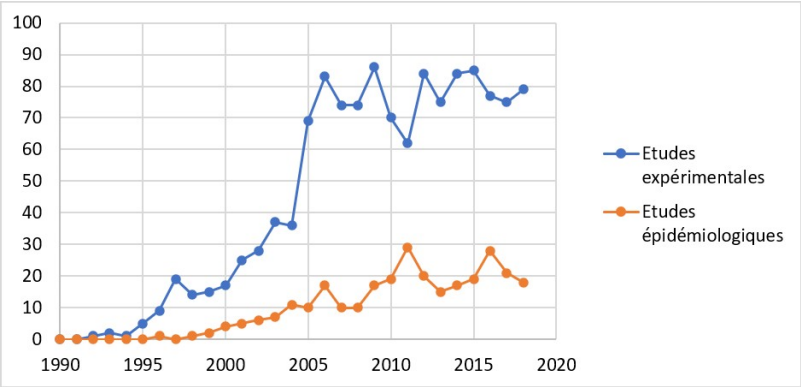

Figure 3. number of publications per year from 1990 to 2018 (experimental and epidemiological studies). [Source: graph based on information available in the EMF-Portal database]

The evolution of the number of scientific publications since 1990 illustrates the importance of the research activity related to the biological and health effects of waves at the frequencies of wireless communication technologies (Figure 3).

2.3. How is risk assessed?

Risk is assessed based on **all the scientific data** published worldwide. For this purpose, health agencies or reference institutions bring together groups of specialists from various backgrounds (biologists, physicians, epidemiologists, physicists, etc.). They take stock of the state of knowledge and produce **collective expert reports**. The data analysis method follows a rigorous process that is specified in the reports. In the **media**, effects observed in one study and then not confirmed later are regularly reported **without nuance or contextualization** in relation to the data as a whole. Rebuttals, when they do occur, are very rarely reported [6]. Moreover, it is always possible to publish an article in a scientific journal, particularly in generalist journals or those not specialised in bio-electromagnetism, even if its content is dubious [7]. It is therefore preferable to refer to collective expert reports and the conclusions of agencies.