ANSES Opinion
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The Director General

Maisons-Alfort, 12 April 2021

OPINION
of the French Agency for Food, Environmental and Occupational Health & Safety

on "Population exposure to electromagnetic fields associated with the deployment of 5G communication technology and the related health effects"

ANSES undertakes independent and pluralistic scientific expert assessments.
ANSES primarily ensures environmental, occupational and food safety as well as assessing the potential health risks they may entail.
It also contributes to the protection of the health and welfare of animals, the protection of plant health and the evaluation of the nutritional characteristics of food.
It provides the competent authorities with all necessary information concerning these risks as well as the requisite expertise and scientific and technical support for drafting legislative and statutory provisions and implementing risk management strategies (Article L.1313-1 of the French Public Health Code).
Its opinions are published on its website. This opinion is a translation of the original French version. In the event of any discrepancy or ambiguity the French language text dated 12 April 2021 shall prevail.

On 9 January 2019, ANSES received a formal request from the Ministries of Health, the Environment and the Economy to undertake the following expert appraisal: "Exposure to electromagnetic fields associated with the deployment of 5G communication technology and the related health effects".

1. BACKGROUND AND PURPOSE OF THE REQUEST

The deployment of 5G (fifth generation) network infrastructure aims to foster the development of innovative services for both consumers and businesses in a range of fields including healthcare, media, transport and the industries of the future. Two main trends spurred the mobile technology industries to develop a new-generation communication network: first, the significant growth in wireless services requiring networks of increased speed and capacity, able to deliver content-rich services including videos, and, second, the expected growth of the Internet of Things (IoT), fuelling the need for mass device connectivity and ultra-reliable low-latency connectivity for applications such as connected cars, industrial automation, and some healthcare applications.

These developments do not only require the frequencies already used by existing generations of mobile telephony; they also need new frequency bands. Among them, two frequency bands have already been identified for deployment in France: the 3.5 GHz band (3.4 - 3.8 GHz) will provide 5G mobile broadband coverage, while the 26 GHz band (24.25 - 27.5 GHz) will make it possible to connect a large number of devices and to provide low-latency communications in geographical areas of limited size.

As well as changing the ways in which the population is exposed, these technological developments will require the adaptation of the methods used to measure and assess exposure.

To support the deployment and development of 5G, the government presented a national 5G roadmap on 16 July 2018[1]. One of the four strands set out by the government is to "ensure transparency and dialogue in relation to deployment and public exposure".

The request to ANSES comprises three points:

1. A description of the characteristics and type of signals emitted.
2. An assessment of the public exposure levels associated with 5G mobile communication technology.
3. A review of existing knowledge on the health effects associated with exposure to electromagnetic fields in the 3.5 GHz and 26 GHz bands.

In view of the shared nature of their concerns, ANSES and the ANFR (French National Frequency Agency) decided to undertake a joint scientific programme with a twofold aim: to describe the technical characteristics of 5G technology, particularly the radiating devices specifically developed for 5G as part of pilot deployments, and also to assess population exposure levels based on measurements taken in pilot areas without users, as part of exploratory tests.

The response to the request will therefore take the form of complementary reports by ANSES and the ANFR:

- two ANFR reports: a general presentation of 5G from the perspective of public exposure (ANFR, 2019)[2], and the first results of the exposure measurements carried out during 5G pilot deployments (ANFR, 2020)[3].
- two reports from ANSES, a preliminary report published in January 2020[4], identifying the studies available on the possible health effects associated with exposure to electromagnetic fields in the 3.5 GHz and 26 GHz bands, and the report relating to this expert appraisal, which seeks to assess the level of evidence associated with the effects studied in the scientific literature.

[1] https://www.economie.gouv.fr/files/files/Actus2018/Feuille_de_route_5G-DEF.pdf.
[2] Assessment of the exposure of the general public to 5G electromagnetic waves. Part 1: general presentation of 5G. ANFR, July 2019.
[3] Assessment of public exposure to 5G electromagnetic waves. Part 2: first measurement results on 5G pilots in the 3400 - 3800 MHz band. ANFR, April 2020.
[4] Population exposure to electromagnetic fields associated with the deployment of 5G communication technology and the related health effects. Preliminary study. ANSES, January 2020.

In its preliminary report published on 27 January 2020, ANSES presented the progress made in its work, with particular emphasis on the inventory of the scientific studies available. It also outlined the scientific work programme conducted in collaboration with the ANFR.

ANSES had already highlighted the lack of available scientific data on the possible biological and health effects associated with exposure to frequencies around 3.5 GHz. This current expert appraisal therefore sought to assess the possibility of adapting the results of previous studies on the risks associated with a variety of technologies (3G, 4G, WiFi, body scanners, etc.) using frequencies close to the 3.5 GHz band, from 0.8 to 2.45 GHz, in order to apply them to 5G innovations. For higher frequencies of between 20 and 60 GHz, more data are available in existing literature. The expert appraisal work therefore sought to analyse these data in order to assess the possible health impacts associated with exposure in the 26 GHz band.

In this way, the Agency identified two separate risk assessment fields corresponding to the two new 5G frequency bands – around 3.5 GHz and around 26 GHz – and their different modes of exposure.

2. ORGANISATION OF THE EXPERT APPRAISAL

The expert appraisal was carried out in accordance with French Standard NF X 50-110 “Quality in Expert Appraisals – General requirements of Competence for Expert Appraisals (May 2003)”.

ANSES analyses interests declared by experts before they are appointed and throughout their work in order to prevent risks of conflicts of interest in relation to the points addressed in expert appraisals.

The experts’ declarations of interests are made public via the website: https://dpi.sante.gouv.fr/.

This expert appraisal falls within the sphere of competence of the Expert Committee (CES) on “Physical agents and new technologies”. ANSES mandated a Working Group of experts on 5G to undertake this expert appraisal under the leadership of the CES.

2.1. Working Group

The Working Group was formed following a public call for applications. The experts in this group were recruited for their scientific and technical skills in the areas of electromagnetic fields, ophthalmology, neurosciences, dermatology, genomics, membrane biology and social sciences. Set up in January 2020, the Working Group held 14 plenary sessions between January 2020 and March 2021.

2.2. External contributions

ANSES commissioned a study[5] from LISIS (Interdisciplinary Laboratory in Social Sciences and Innovation – CNRS (French National Centre for Scientific Research) UMR joint research unit, INRAE (National Research Institute for Agriculture, Food and the Environment) and Gustave Eiffel University) to analyse the controversy associated with the deployment of 5G technology

[5] Research & Development Agreement No. 2017-CRD-11.

and to quantify media coverage between 2019 and 2020. The study produced two reports, which were used in this expert appraisal: Demortain, Féron 2020; Demortain 2021.

2.3. Collective expert appraisal

The methodological and scientific aspects of the expert appraisal work were regularly submitted to the CES. The report produced by the Working Group takes account of the observations and additional information discussed with CES members. This expert appraisal work was therefore conducted by a group of experts with complementary skills.

2.4. Expert appraisal method

The deployment of 5G technology will involve several frequency bands.

Alongside the frequency bands around 3.5 GHz and around 26 GHz initially presented by mobile operators and other industrial players in their 5G deployment plans, more frequencies were added in late 2020 while the expert appraisal was in progress. The additional band of frequencies between 700 and 2100 MHz is already used in 3G and 4G mobile telephony in particular.

To study the possible health effects of exposure to 5G technologies in the 700 - 2100 MHz band, the Working Group relied on previous ANSES expert appraisals concerning the health effects associated with radiofrequency electromagnetic fields (ANSES, 2013 and 2016) and on recent international expert appraisal reports. It should also be noted that an expert appraisal on the carcinogenic effects of radiofrequencies (covering all frequency bands) is currently being examined by ANSES.

For the 3.5 GHz band specifically, the Working Group found only a very small number of scientific publications studying the possible health effects in this frequency range. They therefore looked at the possibility of using the results obtained by studies on neighbouring frequencies. For this reason, the Working Group analysed the impact of frequency on the physiological and biological responses of humans and animals in frequency bands close to those used in mobile telephony (900 MHz - 2.5 GHz), for which a substantial amount of literature is available. Their conclusions concerning the possible health effects of exposure to electromagnetic fields in the band around 3.5 GHz are therefore based on these two types of data: the small number of scientific studies available (3.5 GHz band) and their analysis of the impact of frequency on the biological or physiological effects observed (900 MHz - 2.5 GHz band).

Last, for the frequency band around 26 GHz, the Working Group considered all publications involving frequencies of between 18 and 100 GHz. The studies conducted in this frequency band relate in particular to radar applications or therapeutic devices.

- **Literature search and analysis**

This expert appraisal is based primarily on an analysis of international scientific literature on the biological and health effects of exposure to electromagnetic fields in the frequency bands used by 5G technologies. To this end, a literature search was carried out, taking account of various data sources:

- publications from the literature search equation implemented by the Working Group;

- publications from the bibliography of the ANSES interim report (ANSES, 2019)[6];
- publications from the bibliography of the Simko and Mattsson review (Simko and Mattsson, 2020)[7];
- publications forwarded by members of the Dialogue Committee on "Radiofrequencies and Health".

The literature search was carried out for the period between January 2012 and July 2020. A number of key studies published between July 2020 and March 2021 were also included in cases where they were deemed relevant and of satisfactory quality. The search engines used for this expert appraisal were *Scopus*[8] (*http://www.scopus.com/home.url)* and *PubMed*[9].

The documents taken into account for the expert appraisal are scientific articles and journals published in English or French in peer-reviewed journals, without prejudging their impact factor.

The experts making up the Working Group jointly analysed and discussed the articles listed. Each article was selected using its title and abstract in order to determine its relevance to the issue addressed. The articles selected were then analysed in detail by two experts. A third expert with the competence necessary to assess the quality of the exposure system then completed the critical analysis of each article. The analyses were then discussed in plenary meetings, in order to collectively assess the methodological quality of the publication.

In their analysis of the publications, the experts excluded those with major methodological weaknesses, such as inadequate exposure systems or failure to take sufficient account of confounding factors.

■ Assessing the level of evidence for a given health or biological effect

The general method used in this expert appraisal to assess the level of evidence of a health effect, has been routinely implemented and updated by ANSES over several years. Detailed descriptions can be found in the expert appraisals on radiofrequencies and health (ANSES, 2013)[10], on the health of children exposed to radiofrequencies (ANSES, 2016)[11], and on the effects of exposure to low-frequency electromagnetic fields (ANSES, 2019)[12].

The results of the studies considered by the experts of the Working Group to be useful to the assessment of the health effects of 5G technologies are briefly presented for each effect studied.

For a given health effect, all the studies available on animal models were taken into consideration. The evidence supporting a link between exposure to 5G and the effect under

[6] ANSES interim report on population exposure to electromagnetic fields associated with the deployment of 5G communications technology and the associated health effects, ANSES, 2019 (in French).
[7] "5G Wireless Communication and Health Effects—A Pragmatic Review Based on Available Studies Regarding 6 to 100 GHz", Int J Environ Res Public Health. 2019 Sep; Simko and Mattsson.
[8] *Scopus* is a search tool providing access to a multi-disciplinary scientific bibliographic database, listing publications in the fields of biology and medicine, as well as human and social sciences.

[9] PubMed is a search engine primarily accessing publications in the fields of medicine and biology.

[10] Collective expert appraisal report, "Radiofrequencies and health", update of the expert appraisal, ANSES, 2013.
[11] Collective expert appraisal report, "Exposure to radiofrequencies and children's health", ANSES, 2016.
[12] Collective expert appraisal report, "Health effects associated with exposure to low-frequency electromagnetic fields", ANSES, 2019.

consideration was then determined, using a decision tree. Following this analysis, the level of evidence for each effect was classified in one of four categories:

- sufficient evidence supporting the existence of an effect;
- limited evidence supporting the existence of an effect;
- insufficient evidence supporting the existence of an effect;
- no effect indicated by the available data.

■ **Characterisation of exposure**

To characterise population exposure to the electromagnetic fields emitted by 5G technologies, the collective expert appraisal relied primarily on a summary of the data published in the scientific literature, and in particular the report produced by the ANFR (ANFR, 2020).

3. ANALYSIS AND CONCLUSIONS OF THE CES

3.1. Conclusions of the CES and of the Working Group

3.1.1. Deployment of 5G and the regulatory framework

■ **Deployment**

In April 2019, South Korea became the world's first country to deploy 5G in the 3.5 GHz band. Today, around 90% of the population has access to 5G technology. Other countries have also started 5G deployment at different paces and in line with their own strategies.

The action plan set out by the European Commission made provision for a coordinated commercial roll-out of 5G in 2020. However, international tensions – between China and the United States in particular – along with requests for deferment from some politicians and members of the public (petitions, requests for a moratorium, appeals, etc.) may have contributed to slowing down the deployment of 5G within the European Union (EU).

In France, the Council of State dismissed the appeals filed against the allocation of new 5G frequencies in December 2020.

Following the auctions that took place in October 2020, the first commercial services were made available to the public in November of the same year. As of 31 January 2021, the frequency bands concerned are 700 MHz (Free Mobile), 2100 MHz (Bouygues Telecom, Orange and SFR) and 3.5 GHz (all four operators).

■ **Exposure limit values**

Regarding public exposure to mobile telephony (base stations and mobile phones), many countries around the world, including France and most other European Union countries, apply the guidelines set out by the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 1998)[13] for limiting exposure to electromagnetic fields. However, a number of European countries apply lower limits than those recommended by the EU Council (Belgium, Bulgaria, Croatia, Grand Duchy of Luxembourg, Greece, Italy, Lithuania, Poland

[13] ICNIRP guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz). Published in: Health Physics 74 (4):494-522; 1998.

Slovenia). Regulations differ in terms of the actual limit values, depending on frequency, place of application, monitoring procedures and, where applicable, the minimum level of power or EIRP (equivalent isotropically radiated power)[14] below which the limits do not apply.

In 2020, the ICNIRP published an update of its guidelines for limiting exposure to radiofrequencies[15]. The reference levels (electric field) for the frequencies used in mobile telephony vary between 36.4 V/m at 700 MHz and 61 V/m at 2.6 GHz.

3.1.2. Public controversy associated with the deployment of 5G

The expert appraisal report includes an exploratory analysis of the public controversy associated with the deployment of 5G, based primarily on the data and analyses of two research reports (Demortain and Féron, 2020;[16] Demortain 2021[17]) conducted by the Interdisciplinary Laboratory in Social Sciences and Innovation (LISIS – CNRS UMR, INRAE and Gustave Eiffel University).

5G is a mobile technology with a difference. The combination of technical advances and new uses lends itself to controversy. 5G developers present these changes as sources of technical, economic and social progress. However, they take on other meanings in the public arena. Public debate views them as sources of concern, particularly from the health, environmental, economic and political standpoints.

The analysis draws upon three data sources to describe the controversy: a series of interviews with players involved in the controversy at different levels, documents from these organisations and individuals or other entities involved in this issue, concerning 5G or the controversy, and finally different media corpuses (press, social media, popular science).

An analysis of these corpuses highlights a number of key characteristics specific to the controversy around 5G. First, the multidimensional nature of public protests. Criticisms target three main aspects: (1) the technical system itself; its intrinsic properties are controversial as sources of potential risk; (2) the decision-making process with the deployment set in train without public consultation or an expert appraisal of risks; (3) the social aspects of the programme, which inspires considerable scepticism in its opponents, in terms of both energy efficiency and use.

Although the controversy over 5G is part of a broader controversy around electromagnetic fields in general, where it is simply the latest stage in discussions, following on from base stations, WiFi and Linky smart electricity meters, it nevertheless stands apart for its ecological aspects. Alongside the question of health risks, 5G raises further questions relating to energy consumption and an exploitation of resources that would have a negative impact on the environment.

Further, this controversy is played out very much in the public eye. It is fuelled by media coverage of 5G issues and also by the new forms of collective mobilisation developing in the

[14] Equivalent isotropically radiated power (EIRP) is the maximum amount of power radiated from an antenna in a single direction that would have to be applied to an isotropic antenna to obtain the same electric field in that direction.
[15] ICNIRP guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz). Published in: Health Physics 118(5): 483–524; 2020. Published ahead of print in March 2020: Health Physics 118(00):000–000; 2020.
[16] "The risks of deployment. The emergence of a controversy around 5G in France", Demortain and Féron, LISIS, 2020 (in French).
[17]"Media coverage of the 5G issue in France. A quantitative analysis", Demortain, 2021 (in French)

digital public space, involving a multitude of players and leading political parties to take up a position.

Above all, the analysis of various media arenas (the press and social media) underlines the political dimension of this controversy. Alongside the questions relating to environmental and health risks, the protest movement is demanding the option to choose – or to refuse – the deployment of the technology in question.

This question of free choice cannot be limited to the deployment of 5G alone, given that this technology is often presented – by both its supporters and its opponents – as a step towards a broader programme for a digitised society. The debate around 5G technology is a debate around a specific social model: an all-digital, all-connected society and everything that this implies in terms of living spaces saturated by accumulated exposure to electromagnetic fields, higher energy consumption driven by a multitude of uses, and also widespread surveillance. As a result, the conflict around 5G probably stems from the fact that many people feel that all these changes are being imposed on them, and that they are powerless to choose or to play any role in the process of construction.

3.1.3. Assessment of the potential health effects associated with the deployment of 5G

In the conclusions to the expert assessment work presented below, the issues specific to each of the three frequency bands concerned by the deployment of 5G technology in France are considered in turn: first, the frequencies already used by 3G and 4G mobile telephony (the 700, 800, 1800 and 2100 MHz bands), followed by the new bands used specifically for 5G: the frequencies around 3.5 GHz (3.4 GHz to 3.8 GHz) and then those around 26 GHz.

No data from scientific studies are currently available on the possible health effects of exposure to electromagnetic fields specifically in the new frequency bands to be used for 5G. For this expert appraisal, the Working Group therefore relied on existing literature concerning wider frequency bands and on the results of expert appraisals conducted on neighbouring frequency bands. The expert appraisals conducted by ANSES in previous years on the possible effects of exposure to radiofrequencies (particularly in the 8.3 kHz - 2.5 GHz frequency band) indicate that the only proven effects (causal link demonstrated) of radiofrequencies are thermal effects, i.e. associated with the heating of biological tissue.

- **Health effects of 5G deployment in frequency bands between 700 and 2100 MHz**

To study the possible health effects of exposure to 5G technologies in the 700 - 2100 MHz band, the Working Group relied on previous ANSES expert appraisals on the health effects of radiofrequency electromagnetic fields (ANSES, 2013 and 2016) and on recent international expert appraisal reports.

What are the data sources available?

In France, the deployment of 5G mobile networks using the frequency bands between 700 and 2100 MHz began in[18] autumn 2020, when this expert appraisal was already under way. As ANSES had already produced a number of expert appraisals on the health effects of

[18] Many applications were filed with the ANFR at this time concerning the installation or modification of base stations for 5G communication in the 700 or 2100 MHz frequency bands.

electromagnetic fields covering these frequencies, the Working Group relied on previous ANSES expert appraisals published in recent years (ANSES, 2013 and 2016), as well as on recent expert appraisal reports published by foreign and international organisations.

What can we say about exposure to 5G at these frequencies?

In theory, taking into account the technical data available to the Working Group, concerning the infrastructure and the operation of 5G mobile networks, little variation is expected in the levels of environmental exposure associated with emissions from base stations, in identical conditions (user density, traffic, etc.), regardless of whether the base stations are emitting 3G, 4G or 5G signals (see chapter 4.3 of the expert appraisal report).

What possible health effects have been studied and assessed?

In humans, the main health effects of exposure to electromagnetic fields studied and assessed for this frequency band by the scientific literature and expert appraisals are: the risk of cancer, changes in brain function (cognition, memory, electrical activity), reduced fertility and a number of symptoms associated with electromagnetic hypersensitivity.

In animals, the effects studied mainly concern the brain (behaviour, cognition, memory), oxidative stress, genotoxicity and carcinogenesis. Finally, *in-vitro* studies on cells from animal or sometimes human tissue, focused mainly on cell death caused by apoptosis, oxidative stress or genotoxicity.

Does the deployment of 5G at these frequencies present a health risk?

The results of previous expert appraisals conducted by ANSES on the health effects of exposure to radiofrequencies (8.3 kHz - 2.5 GHz band) are relevant to 5G deployment in the 700 - 2100 MHz band, although the Working Group was unable to identify any studies relating to the frequency of 700 MHz. Furthermore, the levels of environmental exposure for 5G are likely to be comparable with those of earlier mobile telephony technologies for the 700 - 2100 MHz frequency range.

The institutional reports published on these frequencies in other countries in the period since the latest expert appraisals by ANSES do not show a causal link between exposure to the electromagnetic fields emitted by mobile technologies and the appearance of health effects[19].

- **Health effects of 5G deployment in the 3.5 GHz frequency band**

For the frequency band around 3.5 GHz, the Working Group found only a very small number of scientific publications studying possible health effects in this frequency range. For this reason, they examined the possibility of using the results of studies obtained for neighbouring frequencies. The Working Group therefore analysed the impact of frequency on the physiological and biological responses of humans and animals in frequency bands close to those used in mobile telephony (900 MHz - 2.5 GHz), for which a substantial quantity of literature is available. Their conclusions concerning the possible health effects of exposure to electromagnetic fields in the band around 3.5 GHz are therefore based on these two types of data: the small number of scientific studies available (3.5 GHz band) and an analysis of the

[19] Please refer to the expert appraisal reports published by ANSES on the effects of radiofrequencies for a definition of the terms used (ANSES, 2013).

impact of frequency on the biological or physiological effects observed (900 MHz - 2.5 GHz band).

Are there any data relating to 5G exposure in this frequency band?

In France, commercial services were launched only recently in the 5G mobile phone network using the frequency band around 3.5 GHz (1,594 sites as of 31 January 2021)[20], so the resulting exposure to electromagnetic fields is not representative today of what it will be when a large number of users are connected.

A number of simulations have nevertheless been conducted (ANFR, 2020)[21] to assess the average field strength in a number of environments, such as urban areas, for example. Based on the hypothesis set out concerning the increase in data exchanges, based on an extrapolation of current 4G consumption, the average level of exposure to the electric field would be around 1.5 V/m (ANFR, 2020). This level is comparable to that of the current 4G network, owing primarily to the faster throughput of 5G, with its directional beams. Nevertheless, these simulations show that the number of atypical points (exposure to electromagnetic fields greater than 6 V/m) could be between 0.6 and 1.1% higher than for 4G.

The measurements taken in a number of countries (notably South Korea and the UK) in which 5G has already been rolled out tend to confirm the values of these simulations. However, these measurements are still few in number. In South Korea, for example, where 5G has now been deployed for several months in dense urban areas, the strongest electric field measured was 2.1 V/m, well below the regulatory exposure limit value of 61 V/m at this frequency.

Concerning cumulative exposure to 3G, 4G and 5G technologies in France, the results of simulations (ANFR, 2020) for different 5G deployment scenarios indicate, based on these hypotheses, that the launch of 5G could lead to a limited increase in the average exposure to electromagnetic fields, which would rise from 1.3 V/m to 1.7 V/m[22].

What data on possible health effects are available in this frequency range in scientific literature?

Existing scientific literature concerning frequencies of or around 3.5 GHz is made up of just five studies in widely varying fields. This is not sufficient to be able to assess the level of evidence concerning the possible health effects at this specific frequency.

In terms of health effects, can the knowledge available for frequencies below 2.5 GHz be adapted to 3.5 GHz?

- *Is there a significant difference concerning the absorption of electromagnetic energy (particularly with reference to the penetration depth) at 3.5 GHz compared to previous generations of mobile wireless systems (e.g. 2G-4G)?*

The penetration depth of an electromagnetic field into the body is lower at 3.5 GHz than at the lower frequencies used by existing mobile technologies. For example, the penetration depth at 3.5 GHz, is around 40% lower than at 900 MHz. Moreover, because the wavelengths are

[20]https://www.arcep.fr/cartes-et-donnees/nos-cartes/deploiement-5g/observatoire-du-deploiement-5g-fevrier-2021.html.
[21] "Assessment of the exposure of the general public to 5G electromagnetic waves. Part 2: first measurement results on 5G pilots in the 3400 - 3800 MHz band. ANFR, April 2020.
[22] The regulatory exposure limit value at 3.5 GHz is 61 V/m.

shorter at 3.5 GHz, the distribution of absorbed power in the tissues could be more heterogeneous.

In the case of local body exposure to nearby sources (e.g. a mobile phone), the variability in absorption caused by variations in the parameters affecting exposure (phone model, distance of use, close to the head, the trunk or the limbs, use of adaptive power control, etc.) is thought to be greater in theory than the variability related to differences in frequency. However, few dosimetric studies to date provide a detailed analysis of the exposure of different tissues to the electromagnetic fields emitted by mobile phones in the frequency band around 3.5 GHz.

- *Are there any differences between the radiofrequency signals emitted by 5G systems at 3.5 GHz and those emitted by earlier mobile wireless systems (e.g. 2G-4G) that could have an impact on interactions with the human body?*

The characteristics of the radiofrequency signals used by 5G technology are complex, but similar to those of the signals emitted by 4G technology. However, it would be worth studying in greater detail the possible role played by the intermittence of the radiofrequency signals used in mobile communications on biophysical interactions, since this intermittence depends on the mode of transmission and the frequency range.

- *Are the biological effects sometimes observed linked to the frequency of the electromagnetic fields?*

The Working Group looked for any links between the carrier frequency of the electromagnetic fields and the occurrence of biological effects, in the frequency range close to 3.5 GHz (between 845 and 2450 MHz). Based on a bibliography of articles studying at least two frequencies and showing the biological effects of radiofrequencies, studies of cellular and molecular effects frequently suggest that the intensity of these effects increases with the frequency. However, studies on behavioural and neurophysiological effects in animals or humans do not show a link between the frequency and the existence of the effects studied. There is therefore a level of uncertainty concerning the role of frequency in the occurrence of biological and physiological effects in humans.

Does the deployment of 5G in the 3.5 GHz band present a health risk?

The data available today do not allow us to draw any conclusions on the existence of health effects associated with the frequencies used by existing mobile technologies. It seems difficult to extrapolate the results of scientific studies obtained at different albeit similar frequencies, in order to draw conclusions on any potential biological, physiological, behavioural and – a fortiori – health effects in the frequency band around 3.5 GHz.

Nevertheless, taking account of:

- the data available on health effects in the frequency bands for which the penetration depth is of the same order of magnitude as in the frequency band around 3.5 GHz, and
- the fact that the first exposure data available in countries where 5G is already deployed in the 3.5 GHz band do not currently show a significant increase in the average level of population exposure associated with the significant number of electromagnetic field sources,

the Working Group considers that it is unlikely, at this stage, for the deployment of 5G in the frequency band around 3.5 GHz to constitute a new health risk.

However, the intermittence of wireless technology signals could influence all biological responses. This issue has been little investigated to date, and remains an unanswered question in health risk assessment.

- **Health effects of 5G deployment in frequency bands around 26 GHz**

In the absence of exposure data and scientific studies on the possible health effects in the 5G frequency band around 26 GHz, the Working Group considered all publications using frequencies between 18 and 100 GHz.

What are the data sources for the frequency band around 26 GHz?

Regarding exposure, no exposure data for the frequency band around 26 GHz are currently available, since the deployment of 5G applications is still at the planning stage. Nevertheless, the Working Group has begun an analysis of the possible characteristics of future exposure to 5G systems in the frequency band around 26 GHz, in order to formulate an initial qualitative assessment of probable exposure in this frequency band (see next question).

Regarding the possible health effects, there is no published work to date studying the effects of 5G in the 26 GHz band. For this reason, the Working Group considered an extended frequency band, from 18 to 100 GHz. As a result, the data gathered include wide disparities in terms of frequencies, technologies, and the types of effects studied.

What hypotheses could be made concerning future exposures to 5G systems in the frequency band around 26 GHz?

Exposure to electromagnetic fields associated with 5G applications is not the same in the 26 GHz band as in the other frequency bands (700 MHz to 3.5 GHz), since the waves penetrate to a depth of around one millimetre, leading to exposure of the surface layers of the skin or eyes. A predictive analysis of the experimental data and simulations concerning exposure to distant sources (distances of several metres between the source and the person) shows that the power densities absorbed by the skin or eyes will be low and will cause only a slight increase in temperature (around one thousandth of a degree Celsius).

Regarding exposure to nearby sources (e.g. mobile phones), electromagnetic simulations based on the coupling between the head or hands and the built-in miniature antennas suggest that near-field exposure levels will be lower than those of 3G/4G technologies.

All these results will need to be confirmed using, for example, experimental data from the 14 test sites authorised by ARCEP[23] over a period of three years, for which the first results are expected by 2022.

What are the health effects studied in the band around 26 GHz (18 to 100 GHz)?

The scientific literature available mainly studies the effects on the skin, eyes, membranes, central nervous system and cells from various human or animal tissues (skin, neurons, cornea, etc.).

[23] ARCEP: French regulatory authority for electronic communications and postal and print media distribution

- *Skin*

The studies available are too diverse and too few in number to draw any conclusions concerning possible health effects in the 18 - 100 GHz frequency range on human skin. These studies show no genotoxic effects, although one observed an aneuploidy[24]. No overall effect on the transcriptome was detected, apart from a transient effect (lasting around a few hours) on the quantity of transcripts from some genes involved in the cellular stress response. It is extremely difficult to interpret these results.

- *Eyes*

The studies conducted on cornea and lens cell lines show no effects of exposure to radiofrequencies at 40 and 60 GHz. An *in-vivo* study on rabbits shows thermal effects on the cornea when exposed, but at a very high level of power[25] (10 to 600 mW/cm^2).

- *Central nervous system*

Based on studies focusing primarily on the possible painkilling effects of radiofrequencies (42, 60 and 94 GHz) and their mechanisms, the data available (one study in humans) do not allow us to draw any conclusions as to the existence of an effect of nociception or analgesia. Moreover, *in-vitro* data on neurons in culture from several animal species do not allow us to draw any conclusions on a specific mechanism. Note that the possible effects of millimetre waves on the central or peripheral nervous system can be envisaged through the stimulation of nerve endings within the skin, although these effects have yet to be demonstrated.

- *Genotoxic effects*

Four *ex-vivo* studies investigated exposure to electromagnetic fields at frequencies of between 25 and 60 GHz in human cell lines (fibroblasts, lens cells, corneal cells) and rat leukocytes. These studies detected no genotoxic effects. Nevertheless, a study already cited in the “Skin” section detected aneuploidies in fibroblasts exposed to radiofrequencies. It is not possible to conclude from the evidence available whether or not there is an effect.

- *Effects on membranes*

The studies conducted on cell membranes are too few and too heterogeneous to conclude whether or not there is a biological effect. However, studies on artificial membranes[26] in frequency bands of between 52 and 78 GHz have highlighted both structural and functional modifications (structural change in phospholipids and the ordering of the water molecules bound to the interface; shift in the phase transition temperature).

In view of the results of existing studies on artificial membranes, the increase in membrane permeability observed in a cell line, and the importance of membranes in cellular functions, the CES considers that there is a limited level of evidence for the effects of electromagnetic fields on membranes.

[24] State of a cell with an abnormal number of chromosomes.
[25] To be compared to the limit value of 1 mW/cm².
[26] Artificial membranes vs. cell membranes: artificial membranes are simplified membrane models.

Does the deployment of 5G in the 26 GHz band present a health risk?

The evidence at this time is insufficient to conclude whether or not there are health effects associated with exposure to electromagnetic fields in the frequency band around 26 GHz.

3.2. Recommendations of the CES and of the Working Group

Based on the expert appraisal report prepared by the 5G Working Group, and particularly its conclusions and recommendations, the CES makes the following recommendations for studies and research.

- **Studies to improve the characterisation of exposure**

Considering that:

- very little data are available on exposure to base stations and mobile phones in real-life situations;
- only exposure indicators based on digital simulations are currently available;
- these indicators have yet to be validated or invalidated by field measurements owing to the low level of 5G deployment;

The CES recommends:

- measuring exposure from mobile phones in real-life situations in the different bands to be used for 5G deployment;
- assessing situations of maximum exposure, in particular when installing new base stations for mobile telephony;
- conducting measurement campaigns to quantify the increase in the strength of electromagnetic fields when a large number of users are connected simultaneously to the 5G network;
- implementing a programme to monitor exposure to electromagnetic fields in order to track current and future exposure levels, particularly in situations where 5G is superimposed on pre-existing 3G/4G signals.

- **Experimental studies in humans and animals**

- *For the 700 MHz, 2.1 GHz and 3.5 GHz bands:*

Considering that:

- very few publications have examined the biological or health effects of electromagnetic waves in these frequency bands on *in-vitro* cellular models, in animals or in humans;
- 3.5 GHz waves have a lower tissue penetration depth than lower frequencies;

The CES recommends:

- conducting studies targeting biological, physiological or behavioural effects, with particular emphasis on carcinogenesis, brain function (e.g., cognition, memory, electrical activity), fertility and electromagnetic hypersensitivity, particularly in the 3.5 GHz band, in situations of chronic or acute exposure. Further, in order to study long-term risks in humans, longitudinal studies should be preferred;

- promoting studies on cell cultures and organoids in order to measure parameters such as cell viability and genotoxicity. It would be useful to implement global “omics” approaches without a targeted hypothesis (transcriptomics, proteomics, metabolomics, etc.).

▶ *Concerning the frequency band around 26 GHz:*

Considering that:

- few studies have looked at the 26 GHz band;
- wave penetration is low and that energy deposition is localised on the surface in this frequency band;

The CES recommends:

- conducting further studies in the 26 GHz frequency band in situations of chronic or acute exposure;
- analysing the biological and health effects in animals, targeting the most exposed organs, for example, the skin or the eyes;
- promoting studies into the effects of waves on skin flora: microorganisms that are part of the immune system and that contribute to the health of the skin and the organism by forming a protective barrier to keep out pathogenic germs; studying the adaptive immune response; studying the cellular microenvironment;
- conducting in-depth studies to link the observations made on artificial membranes to the observations made on cells;
- promoting studies on *in-vitro* models (skin, cornea, conjunctiva, etc.) in order to measure parameters such as cell viability and genotoxicity. It would be useful to implement global “omics” approaches without a targeted hypothesis (transcriptomics, proteomics, metabolomics, etc.);
- analysing in humans and/or in animal models the long-term effects of radiofrequencies on the nervous system (behaviour, neurophysiology, nociception).

In addition, for all the frequency bands considered, more studies are required, based on rigorous quality methods (for example, including a simple "thermal effect" control group) to investigate the possible biological effects associated with the intermittent signals from some wireless technologies.

Furthermore, the CES recommends conducting studies that take account of co-exposures of any kind. Looking beyond the question of health effects in humans, it points out that it could be useful to study the possible effects of radiofrequencies on fauna and flora.

Finally, from a general standpoint, the CES underlines that it would be useful to encourage studies and assessments of possible health effects and impacts prior to the deployment of new technologies.

4. AGENCY CONCLUSIONS AND RECOMMENDATIONS

As part of the nationwide deployment of 5th generation (5G) technology for data exchange and communication using electromagnetic waves in the radiofrequency range, the Ministries of Health, the Environment and the Economy asked the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) to carry out an expert appraisal on exposure to

electromagnetic fields and the associated health effects. The nature of the work required the expertise of both the ANFR and ANSES.

As a result, the response takes the form of several complementary documents produced by ANSES and the ANFR:

- two reports by ANFR: a general presentation of 5G from the perspective of public exposure (ANFR, 2019), and the first results of the exposure measurements carried out during 5G pilot programmes (ANFR, 2020);
- a preliminary report by ANSES, published on 27 January 2020, identifying the studies available on the possible health effects associated with exposure to electromagnetic fields in the 3.5 GHz and 26 GHz bands, and the report supporting this opinion, which assesses the level of evidence associated with the effects studied in the scientific literature.

ANSES also points out that it is conducting long-term expert appraisals, updated regularly, on the links between exposure to radiofrequencies and health, particularly in the context of their use for telephony and mobile terminals. The latest reference expert appraisals on this subject are the 2013 update (ANSES, 2013) for the general public, and the 2016 report (ANSES, 2016) specific to exposure to radiofrequencies and child health. In this respect, the Agency underlines that it has started an expert appraisal to update the current state of knowledge on a possible link between exposure to electromagnetic fields and the occurrence of cancer.

The existing work carried out by ANSES on the effects of exposure to radiofrequencies (particularly in the 8.3 kHz - 2.5 GHz frequency band) indicates that the only proven health effects, i.e., those leading to the identification of a causal link based on the weight of evidence, are thermal effects, associated with the heating of biological tissue. The Agency points out that these effects provide a basis, in the current state of knowledge, for setting regulatory exposure limit values to protect the public. It also mentions that its previous opinions and reports recommended additional studies and investigations for certain types of effects, which it may be led to re-examine in the light of new knowledge.

From a methodological standpoint and for the purposes of this expert appraisal, the Agency assessed the weight of evidence concerning the health effects associated with exposure to electromagnetic waves in the frequency bands of interest, based on publications taken from the scientific literature.

ANSES endorses the conclusions and recommendations of the 5G Working Group and of the CES on “Physical agents and new technologies”.

Regarding the three frequency bands to be used for the planned deployment of 5G technologies, the Agency notes the following points in particular.

For the deployment of 5G technology in the frequency bands already used by 3G and 4G technologies, i.e. between 0.7 and 2.1 GHz, the Agency notes that exposure levels are poorly documented, but that the work carried out to date, particularly by the ANFR, suggests that exposure levels are likely to be comparable between 5G and previous technologies. Regarding the health effects, only thermal effects have been proven, associated with high levels of exposure that are not encountered in routine use of mobile technologies. Research and assessment studies are continuing into other potential effects (cancer, brain function, fertility,

electromagnetic hypersensitivity, etc.). In the current state of knowledge, the reports published since the last expert appraisals by ANSES do not show other causal links between exposure to the electromagnetic fields emitted by mobile technologies and the appearance of health effects.

For the frequency band around 3.5 GHz, the documented levels of exposure, which are also few in number, come from the work conducted by the ANFR (simulation, measurements on pilot sites) and, in the case of some data, from other countries in which the technology is deployed. These data show limited increases in exposure levels, which in any case remain well below the regulatory limits. In the absence of sufficient scientific data, already highlighted by ANSES in its preliminary report of 2020, it was not possible to assess the level of evidence regarding the link between exposure and possible health effects in this frequency band. The expert appraisal therefore examined possible adaptations based on data existing for other frequencies. The experts considered that it would be difficult to extrapolate for this frequency band the previous conclusions regarding the biological, physiological, behavioural and – more particularly – health effects. However, given the comparable order of magnitude of the depth of penetration of electromagnetic fields in the body, along with the lack of evidence of a significant increase in average exposure, they considered it unlikely that the deployment of 5G in the frequency band around 3.5 GHz would constitute a new risk factor for health.

Finally, for the frequency band around 26 GHz, existing data are slightly more numerous than for the 3.5 GHz band and are based on a wide variety of studies, none of which are specific to the radiofrequencies used in data transfer, as in the case of 5G. As a result, the investigations carried out were extended to publications covering a wide range of frequencies between 18 and 100 GHz. The Agency notes that exposure in this band, which is not yet used in the trials or deployment of 5G, will concern the surface layers of the body, and that the simulations available suggest low levels of exposure. It will be necessary to confirm this information through the measurements taken as part of 5G trials in the frequency band considered. Regarding the various effects studied (skin, eyes, central nervous system, genotoxicity, membrane permeability), it is not possible to draw a positive or negative conclusion, based on the data available, on any health effects other than the thermal effects mentioned above, potentially associated with exposure to radiofrequencies in the 26 GHz band, with the exception of a limited level of evidence concerning the effect on cell membranes.

The conclusions relating to the different frequency bands therefore indicate – for a variety of reasons based on data availability – that the situation regarding a link between exposure to radiofrequencies and health effects for the frequencies used in the deployment of 5G technology is comparable to that of the frequencies used for previous generations, based on the current state of knowledge.

Regarding the continuation of studies on other families of effects for which further investigation is required, the expert appraisal identified several specific points of particular interest: the possible role played by the intermittence of the signals used by mobile communications on biophysical interactions is worthy of further study; similarly, the limited level of evidence on the permeability of cell membranes also needs to be investigated in relation to the conditions of exposure and possible biological consequences.

In this respect, ANSES draws attention to the many structured recommendations made by experts concerning the pursuit of studies and work relating to the characterisation of exposure and also to the characterisation of the links between exposure and effects, based on

experimental studies in humans and animals. These studies and work are necessary for future progress, specifically in the different frequency bands of interest, with particular emphasis on the specific characteristics of the 26 GHz band, concerning the exposure of surface layers.

In the light of the findings of these studies and, more generally, the production of new scientific knowledge on the links between exposure to radiofrequencies and health effects, ANSES may revise its opinion or initiate new expert appraisals.

In the immediate future, the Agency has decided to organise a public consultation on this opinion and the associated report, mainly with a view to gathering data and remarks. This consultation is motivated by social interest in the subject and also by the possible rapid emergence of new data, given the ongoing commercial or experimental deployment of 5G technology.

The expert appraisal process implemented in the drafting of the report will also be applied to the analysis and exploitation of the feedback from this consultation. Where necessary, supplements may then be added to this document or even to this opinion[27].

Moreover, and from a general standpoint, given the limited amount of data specific to 5G available for its expert appraisal, ANSES points out that the deployment of new technologies should ideally be supported by studies or a documented collection of the literature concerning the links between exposure and health impacts prior to roll-out.

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KEYWORDS

Technologie de communication 5G, cinquième génération, ondes millimétriques, exposition, évaluation des risques sanitaires.

5G communication technology, fifth generation, millimetre waves, exposure, assessment of health risks.

SUGGESTED CITATION

ANSES. (2021). “Population exposure to electromagnetic fields associated with the deployment of 5G communication technology and the related health effects”. (Request 2019-SA-0006). Maisons-Alfort: ANSES14 p.

[27] The notion of a supplemented opinion and/or report refers to a process included in the ANSES expert appraisal procedure, which makes provision for a document of this type to be adopted from an earlier version, while ensuring the traceability of any changes made.