

The Director General

Maisons-Alfort, 14 February 2022

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" updating the opinion of 12 April 2021

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 14 February 2022 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: "Population 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 fifth-generation (5G) 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 are emphasised by mobile technology companies for developing a new-generation communication network: firstly, the sharp growth in wireless services requiring networks of increased speed and capacity, able to deliver content-rich services including videos; and secondly, 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 vehicles, industrial automation and some healthcare applications.

These developments require not only the frequencies already used by current mobile telephone generations, but also new frequency bands. Among them, two frequency bands were initially identified for deployment in France: the 3.5 GHz band (3.4-3.8 GHz) to provide 5G mobile broadband coverage, and the 26 GHz band (24.25-27.5 GHz) to connect a large number of devices and provide low-latency communications in geographical areas of limited size. In 2020, while conducting its expert appraisal, ANSES became aware of the planned deployments in the 700 MHz-2100 MHz band for mobile telephone coverage.

These technological developments will change the population's exposure to electromagnetic fields (new frequencies, active antennas, etc.) and require an adaptation of the methodologies for measuring and estimating this exposure.

To support the deployment and development of 5G, the government presented a national 5G roadmap on 16 July 2018¹. One of the four goals set by the government is to "ensure transparency and dialogue in relation to deployment and public exposure".

The formal request to ANSES was broken down into three parts:

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 French National Frequency Agency (ANFR) 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 to assess population exposure levels based on measurements taken in pilot areas without users.

The expert appraisal also took place in a context of strong societal expectations emerging from the public controversy accompanying the deployment of 5G in France and abroad, which has the dual characteristic of reopening the debate on human exposure to radiofrequencies and involving a wide variety of stakeholders with multiple points of view and questions. For this reason, during preparatory discussions with the ministries behind the formal request, it was planned that, in parallel with the risk assessment work, ANSES would also describe and analyse the questions and mobilisations of citizens and scientists that are developing around 5G.

The response to the request is therefore provided in the form of complementary studies by ANSES and the ANFR:

- several ANFR reports: the first provides a general presentation of 5G from the perspective of human exposure (ANFR, 2019)². The second, published as an interim

¹ https://www.economie.gouv.fr/files/files/Actus2018/Feuille_de_route_5G-DEF.pdf.

² "Evaluation de l'exposition du public aux ondes électromagnétiques 5G. Volet 1 : présentation générale de la 5G" ["Assessment of the exposure of the general public to 5G electromagnetic waves. Part 1: general presentation of 5G"]. ANFR, July 2019.

version in July 2019³ and then updated in April 2020⁴, presents the results of exposure values measured during 5G pilot deployments. In September 2020, the ANFR also published the results of its exposure simulation work in a very dense urban area, the 14th *arrondissement* (district) of Paris, in the context of 4G and 5G network development scenarios⁵. Lastly, in December 2021, it published the first results of public exposure measurements taken before and after the introduction of 5G at 1500 sites in France⁶.

- three reports and two opinions by ANSES: a preliminary report published in November 2019⁷, identified the available studies on the possible health effects of exposure to electromagnetic fields in the 3.5 GHz and 26 GHz bands. An expert appraisal report and associated opinion, published in April 2021, included an assessment of the possible health risks associated with 5G deployment. These two documents were then supplemented and updated following examination of the contributions received following a public consultation on them.

According to ANSES's expert appraisal procedure, the present opinion – supported by the associated report – constitutes an *updated opinion* compared to that of spring 2021. In addition to including the information resulting from the consultation, this update also incorporates the results of several reports and documents published since spring 2021, as well as the finalisation of some work initiated by the expert group.

This opinion and associated expert appraisal report therefore take account of the results of all this additional work.

2. ORGANISATION AND METHOD 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 the "5G" Working Group to undertake this expert appraisal under the leadership of the CES.

³ <https://www.anfr.fr/fileadmin/mediatheque/documents/expacement/CND/Rapport-ANFR-resultats-mesures-pilotes-5G.pdf>.

⁴ <https://www.anfr.fr/fileadmin/mediatheque/documents/5G/20200410-ANFR-rapport-mesures-pilotes-5G.pdf>.

⁵ <https://www.anfr.fr/fileadmin/mediatheque/documents/expacement/rapport-paris14-v1.pdf>.

⁶ <https://www.anfr.fr/fileadmin/mediatheque/documents/expacement/20211214-exposition-5G.pdf>.

⁷ Population exposure to electromagnetic fields associated with the deployment of 5G communication technology and the related health effects. Preliminary study. ANSES, October 2019.

The expert appraisal work was adopted by the CES on "Physical agents and new technologies" at its meeting on 13 January 2022.

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, before the expert appraisal work was adopted by the CES in April 2021.

A report and opinion were published on 20 April 2021, inviting interested parties to comment on this work through a public consultation that ran from 20 April to 1 June 2021.

The Working Group then met again nine times between April and December 2021, to prepare the public consultation, analyse and respond to the comments received, and then update the expert appraisal report for all the information deemed relevant.

2.2. External contributions

ANSES commissioned a study⁸ from the Interdisciplinary Laboratory in Social Sciences and Innovation (LISIS), involving the French National Centre for Scientific Research (CNRS) UMR 9003 joint research unit, the National Research Institute for Agriculture, Food and the Environment (INRAE) and Gustave Eiffel University, in order to analyse the controversy associated with the deployment of 5G technology and 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

Assessing the risk of exposure to radiofrequencies is based on an assessment of both the intrinsic ability of the radiation to damage health (the hazard) and the levels of population exposure.

The physical and technological characteristics of 5G, the availability of data and the tight timeframe for conducting this assessment work led the Working Group to adopt risk assessment methods specific to the three frequency bands planned for 5G deployment (between 700 and 2100 MHz, between 3.4 and 3.8 GHz, and between 24.25 and 27.5 GHz).

⁸ Research & Development Agreement No. 2017-CRD-11.

2.4.1. Literature search and analysis (frequency bands around 3.5 GHz and 26 GHz)

The Working Group conducted a search of the international scientific literature on the biological and health effects of exposure to electromagnetic fields in the frequency bands around 3.5 GHz and 26 GHz. It took different data sources into account:

- publications identified by the literature search equation used by the Working Group;
- publications from the bibliography of ANSES's preliminary report (ANSES, 2019)⁹;
- publications from the bibliography of the Simko and Mattsson review (Simko and Mattsson, 2019)¹⁰;
- publications forwarded by members of the Dialogue Committee on "Radiofrequencies and Health".

The literature search covered 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 (see the associated expert appraisal report for a description of the assessment criteria). The search engines used for this expert appraisal were *Scopus*¹¹ (<http://www.scopus.com/home.url>) and *PubMed*¹². Some references of interest mentioned subsequently in the public consultation were also considered.

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

The two frequency bands considered for the literature search were 3-4 GHz and 18-100 GHz¹³.

The experts in the Working Group collectively 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 completed the critical analysis of each article. The analyses were then discussed in plenary meetings, in order to collectively assess the methodological quality of each publication.

In their analysis of the publications, the experts excluded those with major methodological weaknesses (see the selection criteria in the associated expert appraisal report).

Lastly, the first results of public exposure measurements taken by the ANFR before and after the launch of 5G on 1500 sites in France were also taken into account.

⁹ ANSES preliminary report on population exposure to electromagnetic fields associated with the deployment of 5G communication technology and the related health effects, ANSES, 2019.

¹⁰ "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.

¹¹ *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.

¹² *PubMed* is a search engine primarily accessing publications in the fields of medicine and biology.

¹³ See Chapter 3 of the preliminary report published by ANSES for the justification of these frequency bands; the 18-60 GHz band has been extended in this expert appraisal to 18-100 GHz.

2.4.2. Risk assessment methods specific to the frequency bands in question

■ Frequency band 700-2100 MHz

To identify the possible adverse health effects of exposure to 5G technologies in the 700-2100 MHz band, the Working Group drew on previous ANSES expert appraisals on the health effects of radiofrequency electromagnetic fields ("[Radiofrequencies and health](#)" 2013, "[Radiofrequencies and children's health](#)" 2016, "[Electromagnetic hypersensitivity](#)" 2018, "[High SAR telephones](#)" 2019, in particular) and on summaries provided by international expert appraisal reports (2018-2021) in order to identify any recent developments in knowledge. It should be noted that an expert appraisal on the carcinogenic effects of radiofrequencies (covering all frequency bands) is currently being conducted by ANSES.

The assessment of exposure in the 700-2100 MHz band drew on scientific publications and measurements provided in particular by the work of the ANFR.

■ Frequency band around 3.5 GHz

For the 3.5 GHz band specifically, the Working Group found only a very small number of scientific publications studying the possible adverse health effects in this frequency range (five publications, see procedures and period in 2.4.1). They therefore examined the possibility of using the numerous data available for the frequency band between 900 MHz and 2.5 GHz (see previous ANSES expert appraisal reports 2013, 2016, 2018, 2019, etc.). The Working Group then analysed the possibility that the effects observed in the 900 MHz-2.5 GHz frequency band could also be observed around 3.5 GHz. The conclusions on possible adverse health effects of exposure to electromagnetic fields in the band around 3.5 GHz are therefore based on several types of data:

- the few scientific studies available (3.5 GHz band);
- an analysis of the influence of the frequency on the biological or physiological effects observed in the band between 900 MHz and 2.5 GHz;
- ANSES's previous work in the 900 MHz-2.5 GHz band, based on numerous data;
- biophysical considerations on the interaction of electromagnetic fields with the human body at 3.5 GHz.

The first commercial deployments of the 5G mobile network in the 3.5 GHz band took place in November 2020, while ANSES was conducting its expert appraisal. To date, the number of users and traffic in this band is still limited, meaning that exposure to electromagnetic fields is not representative of what it will be in the future. Scientific publications, data from mobile operators' field experiments monitored by the ANFR and numerical simulations were therefore used to anticipate possible future developments.

■ Frequency band around 26 GHz

Lastly, for the frequency band around 26 GHz, the Working Group considered all the identified publications (see 2.4.1) involving frequencies between 18 and 100 GHz. The data available in the literature, although more numerous than those around 3.5 GHz, were still limited. Nevertheless, the expert appraisal work drew on these data, which are the only ones currently available, in an attempt to assess the possible health impacts of exposure in the 26 GHz band.

The studies conducted in this frequency band relate mainly to radar applications or devices used for therapeutic purposes. This information was supplemented by biophysical data on the specificities of the interactions of these frequency bands with the human body.

To anticipate the exposure of populations to 5G technologies in this frequency band, which has not yet been deployed in France, the Working Group relied on theoretical information, numerical simulations and test measurements available in the publications analysed.

2.4.3. Assessing the level of evidence for a given health effect (around 26 GHz)

"Health" effects are distinct from "biological" effects. Biological effects are molecular, cellular or physiological changes in response to stimulation. A 'biological' effect is within the limits of an organism's ability to maintain the balance of its internal environment (homeostasis) in response to external stresses, and is usually reversible. The existence of a biological effect, especially one observed under experimental conditions, does not necessarily mean that damage will follow, and even less that it will result in an adverse health effect. Indeed, organisms are constantly subjected to a range of internal and external stimuli that can induce one or more normal adaptive biological responses of the cell, tissue or organism. A health effect is only observed when the biological effects exceed the adaptation limits of the biological system in question, leading to negative consequences for the organism. The health effect is the appearance of one or more symptoms that are detrimental to the health of an individual or group of individuals.

Studies describing biological effects were analysed because they contribute to the assessment of the level of evidence for the observed health effects, for example by providing an explanation of the mechanisms potentially involved.

The general method used for assessing the level of evidence for a health effect, applied in this expert appraisal to the frequency band around 26 GHz, is regularly updated at ANSES as part of its appraisals of exposure to electromagnetic fields. Detailed descriptions can be found in the expert appraisals on radiofrequencies and health ([ANSES, 2013](#))¹⁴, on the health of children exposed to radiofrequencies ([ANSES, 2016](#))¹⁵, and on the effects of exposure to low-frequency electromagnetic fields ([ANSES, 2019](#))¹⁶.

The results of the studies selected by the experts of the Working Group for assessing the health effects of 5G technologies in the 26 GHz band are briefly presented here for each effect studied.

For a given health effect, all the available studies on animal models were considered and the evidence supporting a link between exposure to electromagnetic fields and the effect was determined using a decision tree. Following this analysis, the levels of evidence for health effects were classified into one of four categories:

- sufficient evidence supporting the existence of an effect;
- limited evidence supporting the existence of an effect;

¹⁴ Collective expert appraisal report, "Radiofrequencies and health", update of the expert appraisal, ANSES, 2013.

¹⁵ Collective expert appraisal report, "Exposure to radiofrequencies and children's health", ANSES, 2016.

¹⁶ Collective expert appraisal report, "Health effects associated with exposure to low-frequency electromagnetic fields", ANSES, 2019.

- not possible to conclude from the available evidence as to whether or not there is an effect;
- no effect indicated by the available data.

2.5. Public consultation

The Agency organised a consultation, mainly among members of the scientific community and interested stakeholders, on the expert appraisal report and associated opinion published on 20 April 2021. The aim of this public consultation was to gather scientific data and comments. It was prompted both by societal interest in the topic and by the opportunity for the Agency to review the most recent data, given the rapid emergence of such data in the context of experimental or commercial deployment of 5G technology.

The public consultation on the report and associated opinion "Exposure to electromagnetic fields associated with the deployment of 5G communication technology and possible related health effects" ran from 20 April to 1 June 2021.

ANSES specified how to submit comments on the dedicated web page.

This opinion and associated expert appraisal report have therefore now been amended to take account of the scientifically relevant comments made. The report has also been supplemented by an annex on the therapeutic applications of millimetre waves. Another annex presents a quantified review of the comments received during the public consultation.

The "5G" Working Group analysed all the comments complying with the submission conditions and issued a response, which was validated by all the group's experts. These comments and associated responses are available in the form of annexes that can be downloaded from the ANSES [website](#). Contributions, particularly those in report form, that did not comply with the submission conditions were taken into account by identifying the scientifically argued elements to be considered in this expert appraisal.

3. ANALYSIS AND CONCLUSIONS OF THE CES

3.1. Conclusions of the CES and of the Working Group

3.1.1. 5G deployment and regulatory exposure limits

■ 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 its 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.

In France, the Council of State dismissed appeals concerning the roll-out of 5G and the terms and conditions for allocating frequencies in the 3.5 GHz band, in December 2020 and October 2021.

The auctions to allocate frequency bands took place in October 2020, and 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 telephone systems (base stations and handsets), 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)¹⁷ for limiting exposure to electromagnetic fields. The ICNIRP limit values have indeed been included in a recommendation of the Council of the European Union (1999/519/EC¹⁸). However, a number of European countries apply lower limits (Belgium, Bulgaria, Croatia, Grand Duchy of Luxembourg, Greece, Italy and Slovenia) for exposure to sources away from the body (base stations, Wi-Fi hotspots, etc.). These national regulations differ in terms of their actual regulatory values, but also depending on the associated frequency, place of application, monitoring procedures and, where applicable, the minimum level of power or EIRP¹⁹ below which the limits do not apply.

In Recommendation 1999/519/EC, the exposure limits for sources away from the body (reference levels, expressed as electric field strength) for frequencies used in mobile telephone systems range from 36.4 V/m at 700 MHz, to 61 V/m at 3.5 GHz. In 2020, the ICNIRP published an update of its guidelines for limiting exposure to radiofrequencies²⁰.

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;²¹ Demortain 2021²²) conducted by the Interdisciplinary Laboratory in Social Sciences and Innovation (LISIS – CNRS UMR 9003, INRAE and Gustave Eiffel University, Marne-la-Vallée).

5G is not a mobile technology like the others (2G, 3G, 4G), it combines technical advances and new uses that are controversial. 5G developers present these changes as sources of technical, economic and societal 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.

¹⁷ 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.

¹⁸ Council Recommendation 1999/519/EC of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz) – OJEC No L 199 of 30 July 1999.

¹⁹ 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.

²⁰ 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.

²¹ "Les risques du déploiement. L'émergence d'une controverse sur la 5G en France" ["The risks of deployment. The emergence of a controversy around 5G in France"], Demortain and Féron, LISIS, 2020 (in French).

²² "La couverture médiatique du problème de la 5G en France. Une analyse quantitative" ["Media coverage of the 5G issue in France. A quantitative analysis"], Demortain, 2021 (in French)

Three data sources were taken into account: 1) a series of interviews with players involved in the controversy at different levels; 2) documents from different organisations, individuals or other entities involved in this issue, concerning 5G or the controversy; and 3) different media sources (press, social media, popular science).

An analysis of these corpuses highlighted a number of key characteristics specific to the controversy around 5G. Firstly, 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 the risks; 3) the societal aspects of the programme, which inspires considerable scepticism in its opponents, in terms of both energy efficiency and uses.

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, Wi-Fi 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.

Furthermore, 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 digital public space, involving a multitude of players and leading to the expression of political or public views.

Above all, the analysis of various media arenas (the press and social media) underlines the political dimension of this controversy, with the option to choose – or refuse – 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 and resource consumption driven by a multitude of uses, and also the possibility of widespread surveillance and the worsening of digital insecurity and the impact of digital illiteracy. 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. Deployment and uses of 5G: environmental and societal impacts

3.1.3.1. Environmental impacts

While exposure to the electromagnetic waves emitted by 5G technologies gives rise to concerns about possible health effects, their deployment also raises questions about their environmental impact. These questions refer to the impact of telecommunications networks

and, more broadly, of digital development on the environment. Several studies have been published or commissioned recently on the topic, mainly in France²³.

These issues are beyond the scope of this expert appraisal, which was asked to focus on the possible direct health effects of 5G technology. The CES nevertheless wished to highlight these questions, which go beyond the strict framework of 5G and concern all digital developments.

Specific aspects of 5G

With regard specifically to 5G, the High Council on Climate (HCC), in a report published in December 2020²⁴, proposed a quantitative assessment of the carbon impact of 5G, considering different deployment scenarios. According to the HCC, which also underlines the major uncertainties associated with these projections, deployment of 5G could lead to an 18-44% increase in the carbon footprint of digital technologies by 2030²⁵. Currently, half of the carbon impact is due to the production of terminals (smartphones, computers, etc.), a quarter to network and data centre infrastructures, and a quarter to the use of terminals and networks.

In addition, the possible effects of the deployment of mobile telephone infrastructure on fauna, flora and biodiversity warrant further study²⁶.

Environmental footprint of digital technologies

Drawing on a preliminary report by the Senate's information mission on the environmental footprint of digital technologies, the French regulatory authority for electronic communications and postal and print media distribution (ARCEP) pointed out that greenhouse gas (GHG) emissions linked to digital technologies could increase significantly if nothing is done to reduce the footprint: +60% by 2040, i.e. 6.7% of national GHG emissions²⁷. ARCEP also mentioned its desire to "make the environmental issue a new chapter in regulation". The Authority thus hoped to align its action with that of the public authorities, in particular with the French Agency for Ecological Transition (ADEME), with which collaboration should be strengthened via a joint study and joint work as part of the implementation of the Act on the Circular Economy, which requires Internet service providers to inform their subscribers about their consumption and the associated GHG emissions.

In addition to the direct and indirect energy consequences of digital development, its environmental footprint on air quality, soil contamination, water consumption and pollution, and rare metal depletion should be better assessed.

²³ See in particular the reports by the High Council on Climate, ARCEP ("Pour un numérique soutenable" ["For sustainable digital technologies"], December 2020), the government's request to France Stratégie (May 2021) as part of its roadmap on "Environment and Digital Technologies", the report requested by the STOA Panel for the European Parliament, and the report by the *Shift Project* (March 2021, "Impact environnemental du numérique: tendances à 5 ans et gouvernance de la 5G" ["Environmental impact of digital technologies: 5-year trends and 5G governance"]).

²⁴ "Maitriser l'impact carbone de la 5G" ["Controlling the carbon impact of 5G"], report by the High Council on Climate, December 2020.

²⁵ According to the HCC, the carbon footprint of digital tech in France today amounts to around 15 MtCO₂ eq per year, i.e. 2% of the total footprint (749 MtCO₂ eq).

²⁶ Specifically regarding the impact of electromagnetic fields on fauna and flora, see Karipidis, K., Brzozek, C., Bhatt, C.R. *et al.* What evidence exists on the impact of anthropogenic radiofrequency electromagnetic fields on animals and plants in the environment? A systematic map protocol. *Environ Evid* **10**, 39 (2021). <https://doi.org/10.1186/s13750-021-00252-w>.

²⁷ <https://www.arcep.fr/la-regulation/grands-dossiers-thematiques-transverses/lempreinte-environnementale-du-numerique.html>.

3.1.3.2. Societal impacts

The deployment of 5G raises the question of the impact of digital development on health; it also raises ethical questions. While not denying the many virtues of digital technologies and connectivity, the transformation of access to certain services – particularly public services – for example, through means that are exclusively online, risks reinforcing or creating social inequalities, particularly for certain populations (the elderly, economically vulnerable people, etc.). Exposure to the digital world from an early age requires an assessment of the risks associated with the use of connectivity and content. In late 2020, therefore, ANSES undertook an expert appraisal to assess these risks to the health of children and adolescents.

Lastly, it should be noted that the European Union has asked industry to accelerate the development of 5G technologies in order to limit their impact on the frequency bands used by Earth exploration satellites, which are essential for weather forecasting.

3.1.4. Assessment of the potential health risks associated with the deployment of 5G

In the conclusions to the expert appraisal 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 telephone systems (the 700-2100 MHz band), 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.

It is important to note that no data from scientific studies are currently available on the health effects of exposure to electromagnetic fields specifically in the new frequency bands to be used for 5G (around 3.5 GHz and around 26 GHz). The Working Group therefore relied on the results of expert appraisals carried out in neighbouring frequency bands (900 MHz-2.5 GHz) and on existing literature data in wider frequency bands (18-100 GHz).

The conclusions of risk assessments previously conducted by ANSES (particularly in the 8.3 kHz-2.5 GHz frequency band) do not show any proven health effects for exposure below the regulatory limit values.

■ Health risks of 5G deployment in frequency bands between 700 and 2100 MHz

To study the possible adverse 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 (2018-2021).

What are the data sources available?

In France, the deployment of 5G mobile networks using the frequency bands between 700 and 2100 MHz began²⁸ in 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 electromagnetic fields covering these frequencies (ANSES, 2013, 2016, 2019, etc.), the

²⁸ 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.

Working Group referred to these, as well as to recent expert appraisal reports published by foreign and international organisations.

What can be said about exposure to 5G at frequencies between 700 and 2100 MHz?

In theory, given 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, for the same user density and data traffic, regardless of whether the base stations are emitting 3G, 4G or 5G signals.

The initial results of measurement campaigns conducted on different 5G sites were published very recently by the ANFR²⁹. These various sites can be classified into three categories according to the frequency band used for 5G: 700 MHz, 2100 MHz or 3.5 GHz. Measurements were made either with a wideband sensor covering the 100 kHz-6 GHz band, or in the narrow band around the transmitted 5G frequency. The following results are taken from this report.

For the 700 MHz band, the electric field levels of overall exposure measured at 143 sites before and after they were technically operational were 0.69 V/m and 0.76 V/m respectively.

For the 2100 MHz band, the exposure analysis showed that the average field strengths measured after the introduction of 5G remained almost identical to those before its activation, i.e. 1.5 V/m.

However, it is important to stress that the only way to monitor actual exposure levels as 5G develops is through a surveillance programme.

What possible health effects have been studied and assessed?

In the scientific literature and expert appraisal work, the main adverse health effects of exposure to electromagnetic fields in this frequency band investigated and assessed in humans were: 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 biological and health effects studied mainly concerned the brain (behaviour, cognition, memory), oxidative stress, genotoxicity and carcinogenesis. Lastly, *in vitro* studies on cells from animal or sometimes human tissue focused mainly on programmed cell death (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, according to the Working Group, the levels of environmental exposure for 5G are probably comparable with those of earlier mobile telephone technologies for the 700-2100 MHz frequency range.

²⁹ "Étude de la contribution de la 5G à l'exposition du public aux ondes électromagnétiques. Rapport préliminaire" ["Study of the contribution of 5G to exposure of the general public to electromagnetic waves. Preliminary report"] (October 2020 to October 2021) – ANFR, December 2021.

The recent institutional reports published on these frequencies in other countries in the period since the last expert appraisals by ANSES do not show any new causal link between exposure to the electromagnetic fields emitted by mobile technologies and the appearance of adverse health effects³⁰.

■ Health risks 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. They therefore examined the possibility of using the results of studies obtained for neighbouring frequencies. For this reason, the Working Group analysed the impact of frequency on the physiological and biological responses observed in humans and animals in frequency bands close to those used in mobile telephone systems (900 MHz-2.5 GHz), for which a large body of literature was 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, five studies, according to the procedures set out in 2.4.1) and their analysis of the impact of frequency on the biological or physiological effects observed (900 MHz-2.5 GHz band).

Are there any data on 5G exposure in the frequency band around 3.5 GHz?

In France, the first commercial services using the 5G mobile telephone network were launched only recently in the frequency band around 3.5 GHz (1594 sites as of 31 January 2021, 7537 as of 30 September 2021³¹). The resulting exposure to electromagnetic fields is therefore not representative today of what it is likely to be when numerous users are connected.

Simulations of the growth in exposure

Based on assumptions of foreseeable traffic growth associated with the development of 5G, a numerical simulation of spread in an urban environment was conducted (ANFR and CSTB, 2020³²). According to these assumptions of cumulative exposure to the different 3G, 4G and 5G technologies under various 5G deployment scenarios, the introduction of 5G, together with a final development of 4G, would lead to a limited increase in average exposure to electromagnetic fields from 0.8 V/m to 1.7 V/m. It should be noted that these values remain well below the regulatory limit value of 61 V/m at 3.5 GHz.

Nevertheless, these simulations show that the percentage of atypical points (exposure to electromagnetic fields greater than 6 V/m) due to 5G could increase compared with the current situation, from 0.6% to 1.1%.

³⁰ Please refer to the expert appraisal reports published by ANSES on the effects of radiofrequencies for a definition of the terms used (ANSES, 2013).

³¹ <https://www.arcep.fr/cartes-et-donnees/nos-cartes/5g/derniers-chiffres.html>.

³² "Étude de l'exposition du public aux ondes radioélectriques. Simulation de l'évolution de l'exposition du public créée par la téléphonie mobile en zone urbaine très dense (Paris XIV)" ["Study of the exposure of the general public to radio waves. Simulation of the growth in public exposure created by mobile telephone systems in very dense urban areas (Paris XIV)"] ANFR and CSTB, 2020.

Initial data on exposure measurements

The measurement results published recently by the ANFR³³ indicate that for 1062 sites transmitting in the 3.5 GHz band, the average field strength in this band is 0.11 V/m and the maximum value is 2.1 V/m. As this value is very low, the activation of 5G has therefore had very little impact on the overall exposure level, which has increased from 1.16 to 1.17 V/m. This is due to the low number of users served by 5G antennas at the current stage of deployment. Further measurements were therefore obtained through the generation of additional traffic, by downloading a 1 GB file to the measurement point via a 5G terminal. Given the assumption made by the ANFR concerning the growth in exchanged data flows, based on an extrapolation of current 4G consumption, the measurement with the download was averaged over 6 minutes. This download caused an average field strength increase of 0.3 V/m. The measurements taken in countries in which 5G is already operational (mainly South Korea and the UK) tend to confirm the values of this simulation. However, these measurements are still few in number. In South Korea, for example, where 5G was first deployed in April 2019, in dense urban areas, the strongest electric field measured was 2.1 V/m, well below the regulatory exposure limit of 61 V/m at this frequency.

What data on possible health effects for the frequency band around 3.5 GHz are available in the scientific literature?

The available 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 for possible adverse health effects at this specific frequency.

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

- ▶ *Is there a marked 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 (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 2G to 4G mobile technologies. For example, the penetration depth at 3.5 GHz is around 40% lower than at 900 MHz. Moreover, because the wavelengths are 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 telephone), 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 telephones in the frequency band around 3.5 GHz.

³³ "Étude de la contribution de la 5G à l'exposition du public aux ondes électromagnétiques. Rapport préliminaire" ["Study of the contribution of 5G to exposure of the general public to electromagnetic waves. Preliminary report"] (October 2020 to October 2021) – ANFR, December 2021.

- ▶ *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 influence of the intermittent nature of the radiofrequency signals used in mobile communications on biophysical interactions within living organisms.

- ▶ *Is the observation of biological effects linked to the frequency of the electromagnetic fields?*

The Working Group sought to determine whether there was any link between the carrier frequency of the electromagnetic fields and the occurrence of biological effects, in the frequency range close to 3.5 GHz (845-2450 MHz), by analysing articles that had studied at least two frequencies. Studies targeting cellular and molecular effects tend to show that the intensity of the effects increases with the frequency of the electromagnetic fields. However, studies focusing on behavioural and neurophysiological effects in animals or humans do not show any link between the frequency of the electromagnetic fields and the appearance of the effects studied. There is therefore a level of uncertainty concerning the role of the frequency of the electromagnetic fields in the occurrence of biological effects in humans.

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

In the absence of data on specific health effects at 3.5 GHz, the Working Group relied on the numerous scientific publications available in the current mobile communication frequency bands for 2G, 3G, 4G, Wi-Fi, etc. (between 840 MHz and 2.85 GHz) to assess possible associated effects. To date, expert appraisals based on these data have not been able to draw any conclusions about the existence of adverse health effects associated with these frequencies at exposure levels below the regulatory limit values.

To identify possible effects in the frequency band around 3.5 GHz, the Working Group investigated whether the available data (in the 840 MHz-2.85 GHz band) showed a link between the frequency of the waves and the intensity of the effects studied. The physiological or behavioural effects observed (in animals or humans) do not appear to differ from one frequency to another within the 840 MHz-2.85 GHz band. According to current knowledge, therefore, the physiological effects or health risks do not appear to depend on the frequency, between 840 MHz and 2.85 GHz.

Thus,

- the data available on health effects in 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 first exposure data available in countries where 5G is already deployed in the 3.5 GHz band, which do not currently show a large increase in the average exposure of the population due to all the sources of electromagnetic fields;

suggest that the exposure induced by 5G deployment in the frequency band around 3.5 GHz does not constitute a new health risk.

■ **Health risks of 5G deployment in frequency bands around 26 GHz**

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

Regarding exposure, no 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 undertook a debate on the possible characteristics of future exposure to electromagnetic fields emitted by 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. The data gathered therefore include wide disparities in terms of frequencies, technologies and the types of effects studied.

What assumptions can be made about future exposure to the electromagnetic fields emitted by 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 telephones), electromagnetic simulations based on the coupling between the head or hands and the built-in miniature antennas in the devices 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 ARCEP³⁴ over a period of three years, for which the first results are expected in 2022.

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

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

► *Skin*

The studies available in the 18-100 GHz frequency range are diverse and very few in number. These studies, conducted on human skin, report no genotoxic effects, although one observed an aneuploidy³⁵. No overall effect on the transcriptome³⁶ 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. No conclusions can be drawn from these results as to whether or

³⁴ ARCEP: French regulatory authority for electronic communications and postal and print media distribution.

³⁵ State of a cell with an abnormal number of chromosomes.

³⁶ The transcriptome is the set of messenger RNAs resulting from the expression of part of a genome, i.e. the expressed genes.

not there are harmful effects on human skin from exposure to electromagnetic fields at frequencies of 18-100 GHz.

► *Eyes*

The studies conducted on cornea and lens cell lines report no health effects of exposure to radiofrequencies at 40 and 60 GHz. An *in vivo* study on rabbits showed thermal effects on the cornea when exposed at a very high level of power³⁷ (10 to 600 mW/cm²).

► *Central nervous system*

Based on studies focusing primarily on the possible analgesic effects of radiofrequencies (42, 60 and 94 GHz) and their mechanisms, no conclusions can be drawn from the data available (one study in humans only) as to whether there is an effect of nociception or analgesia. Moreover, *in vitro* data on neurons in culture from several animal species cannot be used to draw any conclusions about a specific mechanism. It should be noted that the Working Group did not identify any articles on the possible effects of millimetre waves on the activity of nerve endings in the skin, although it seems highly appropriate to study this type of effect.

► *Genotoxic effects*

Four *ex vivo* or *in vitro* studies on human cell lines (fibroblasts, lens cells, corneal cells) and rat leukocytes did not detect any genotoxic effect of exposure to electromagnetic fields at frequencies between 25 and 60 GHz. Nevertheless, a study already cited in the "Skin" section detected aneuploidies in fibroblasts exposed to radiofrequencies. It is not possible to conclude from the available evidence as to the existence of a genotoxic effect

► *Effects on membranes*

The studies on cell membranes are few in number and vary widely. One of these studies showed an increase in membrane permeability in a cell line. In addition, studies on artificial membranes³⁸ have shown that exposure to electromagnetic fields at frequencies between 52 and 78 GHz leads to both structural and functional alterations (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 these studies, there is a limited level of evidence for the effects of electromagnetic fields on cell membranes.

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

The data available at this time are insufficient to allow any conclusions to be drawn on the existence of adverse health effects associated with exposure to electromagnetic fields in the frequency band around 26 GHz.

³⁷ To be compared to the limit value of 1 mW/cm².

³⁸ Artificial membranes vs. cell membranes: artificial membranes are simplified membrane models.

3.2. Recommendations of the CES and of the Working Group

3.2.1. Recommendations on the use of technologies and on limiting exposure

Considering:

- the conclusions of the expert appraisal expressed above, which on the basis of current knowledge do not show any new health risks associated with exposure to radiofrequencies with the current deployment of 5G;
- uncertainties about the long-term health effects of exposure to radiofrequencies;
- the very preliminary state of the implementation of 5G infrastructure and the use of these networks;

the CES restates the recommendations of previous ANSES expert appraisals on radiofrequencies (mainly the reports published in 2009, 2013, 2016, 2019) and in particular underscores the relevance of the following recommendations:

- call for a reduction in children's exposure to mobile telephones, by advocating moderate use and giving preference to hands-free kits;
- ensure that the current or future deployment of new mobile communication technologies, which overlap with the existing services, are accompanied by a limitation of individual exposure, whether this is environmental or related to the terminals.

3.2.2. Recommendations concerning studies and research

Specifically concerning the new 5G frequency bands, the CES makes the following study and research recommendations, drawing on the expert appraisal report prepared by the "5G" Working Group, and particularly its conclusions and recommendations.

■ Studies to improve the characterisation of exposure

Considering that:

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

the CES recommends:

- measuring exposure from mobile telephones in real-life situations in the different bands to be used for 5G deployment;
- assessing situations of maximum exposure, in particular when installing new mobile telephone base stations;
- 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, 2100 MHz and 3.5 GHz bands:

Considering that:

- very few publications have examined the biological and 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 the molecular, cellular, physiological and behavioural effects of acute or chronic exposure, particularly in the 3.5 GHz band, and mainly in the areas of membrane permeabilisation, carcinogenesis, brain function (e.g. cognition, memory, electrical activity, sleep), fertility and electromagnetic hypersensitivity. Longitudinal studies should be preferred for the study of long-term effects in humans;
- 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"³⁹ approaches without any targeted assumption (transcriptomics, proteomics, metabolomics, lipodomics, epigenomics).

► For the frequency band around 26 GHz:

Considering that:

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

the CES recommends:

- conducting further studies in the 26 GHz frequency band in chronic or acute exposure situations;
- analysing the biological effects and health risks in animals, targeting the most exposed organs, in particular the skin or eyes;
- promoting studies into the effects of waves on skin flora: micro-organisms that are part of the immune system and that contribute to the health of the skin and body by forming a protective barrier to keep out pathogenic germs; studying the adaptive immune response; studying the effects on the cellular micro-environment;
- conducting in-depth studies to link the observations made on artificial membranes to those made on natural membranes of whole 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 any targeted assumption (transcriptomics, proteomics, metabolomics, lipodomics, epigenomics);

³⁹ The "omics" sciences encompass fields of study in biology that are concerned with interactions within and between complex living systems (species, populations, individuals, cells, proteins, RNA, DNA), taking account of the environment to which these living systems are exposed and the ecosystem in which they live.

- 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 control group for the "thermal effect" alone) 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-exposure to electromagnetic fields with other physical or chemical agents.

The CES also mentions that beyond the question of health effects on humans, the possible effects of radiofrequencies on fauna and flora warrants better study.

3.2.3. Recommendations for assessing the environmental and societal impacts

The CES recommends that the environmental footprint of digital development be taken into account and better studied, as well as its societal impacts (ethical and regulatory aspects, etc.).

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

4. AGENCY CONCLUSIONS AND RECOMMENDATIONS

As part of the nationwide deployment of fifth-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 conduct an expert appraisal on population exposure to the corresponding electromagnetic fields and the related health effects.

The nature of the work required the expertise of both the ANFR and ANSES. As a result, the response has been provided through several complementary documents produced by ANSES and the ANFR.

After providing a general presentation of 5G technology, approached from the perspective of human exposure (ANFR, 2019)⁴⁰, the ANFR published a report on the results of the electromagnetic field exposure measurements it carried out during 5G pilot deployments, in an interim version in July 2019⁴¹ and an updated version in April 2020⁴². In September 2020, the ANFR then published the results of its simulations of exposure to these fields in a very dense

⁴⁰ "Evaluation de l'exposition du public aux ondes électromagnétiques 5G. Volet 1 : présentation générale de la 5G" ["Assessment of the exposure of the general public to 5G electromagnetic waves. Part 1: general presentation of 5G"]. ANFR, July 2019.

⁴¹ <https://www.anfr.fr/fileadmin/mediatheque/documents/espace/CND/Rapport-ANFR-resultats-mesures-pilotes-5G.pdf>.

⁴² <https://www.anfr.fr/fileadmin/mediatheque/documents/5G/20200410-ANFR-rapport-mesures-pilotes-5G.pdf>.

urban area, the 14th *arrondissement* of Paris, based on 4G and 5G network development scenarios⁴³. Lastly, in December 2021, it published the first results of measurements of public exposure to electromagnetic fields taken before and after the introduction of 5G at 1500 sites in France⁴⁴.

Meanwhile, ANSES has published the following documents:

- a preliminary report in November 2019⁴⁵, identifying the available studies on the possible health effects of exposure to electromagnetic fields in the 3.5 GHz and 26 GHz bands;
- an expert appraisal report and associated opinion in April 2021, mainly presenting the results of the assessment of the possible health risks associated with 5G deployment. Both documents were the subject of a public consultation;
- following examination of the contributions received after the public consultation, this opinion and associated expert appraisal report, updating the documents published in spring 2021.

In addition, ANSES draws attention to its ongoing expert appraisal work on the links between exposure to radiofrequencies and health, whose results are periodically updated, particularly in the context of their use for telephones and mobile terminals. The latest reference expert appraisals on this topic date from 2013 ([ANSES, 2013](#)) for the general population and 2016 ([ANSES, 2016](#)) for the specific effects on children's health of exposure to radiofrequencies. In this respect, the Agency stresses that it has undertaken expert appraisal work 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) does not show any proven health effects for exposure below the regulatory limit values. In its previous opinions and reports, ANSES had however recommended conducting additional studies on certain types of effects (cognitive functions, brain development, etc.), which it may be led to re-examine in the light of new knowledge.

ANSES endorses the conclusions and recommendations of the "5G" Working Group and 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 700 MHz and 2.1 GHz, ANSES notes that exposure levels are still poorly documented, but that the work carried out to date, particularly by the ANFR, suggests that the levels of exposure to electromagnetic fields emitted by 5G technologies will probably be comparable to those of existing technologies. For these levels of exposure, such as those arising from the use of mobile technologies, the results of the expert appraisals carried out by ANSES have not, to date, revealed any proven health effects. Research and assessment work

⁴³ <https://www.anfr.fr/fileadmin/mediatheque/documents/expacement/rapport-paris14-v1.pdf>.

⁴⁴ <https://www.anfr.fr/fileadmin/mediatheque/documents/expacement/20211214-exposition-5G.pdf>.

⁴⁵ Population exposure to electromagnetic fields associated with the deployment of 5G communication technology and the related health effects. Preliminary study. ANSES, November 2019.

is continuing into certain potential effects (cancer, cerebral dysfunction, infertility, electromagnetic hypersensitivity, etc.).

For the frequency band around 3.5 GHz, the documented levels of exposure come from the work conducted by the ANFR (simulations, site measurements as the technology is deployed) and some data from deployment in other countries. This evidence shows limited increases in overall levels of exposure to electromagnetic fields, which in any case currently remain well below the regulatory limits. Furthermore, the frequency band around 3.5 GHz is close to those used by 2G, 3G and 4G mobile technologies, whose possible effects have been widely documented. It is therefore unlikely that the exposure induced by the deployment of 5G in the frequency band around 3.5 GHz constitutes a new health risk.

Lastly, 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 use of radiofrequencies for data transfer, as in the case of 5G. Based on investigations conducted on a wide range of frequencies between 18 and 100 GHz, the Agency notes that exposure in this band around and above 26 GHz, which is not currently used in France for the deployment of 5G, will concern the uppermost layers of the skin, 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 available studies on the skin, eyes, central nervous system, genotoxicity or membrane permeability, no positive or negative conclusions can be drawn as to the existence of possible health effects associated with exposure to radiofrequencies in the 26 GHz band at a level below the regulatory limit values, except for a limited level of evidence for the effect on artificial cell membranes.

The above findings indicate that, according to current knowledge, the link between exposure to radiofrequencies and health risks for the frequencies of interest for 5G deployment is comparable to that for the frequency bands used by previous generations.

ANSES draws attention to the many structured recommendations made by the experts concerning the pursuit of studies and work on the surveillance and characterisation of exposure, and also on the characterisation of the links between exposure and health effects, using experimental studies in humans and animals. These studies and work are necessary for advancing knowledge, 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.

Based on the findings of these studies, and more generally, the production of new scientific knowledge on the links between exposure to radiofrequencies and health effects (whose availability is subject to the necessary duration of research work), ANSES may revise its opinion or initiate new expert appraisals.

In the meantime, ANSES stresses that good practices in mobile telephone use can help limit exposure to electromagnetic fields. In particular, it reiterates its recommendations following its expert appraisal published in 2016⁴⁶, calling for a reduction in children's exposure to radiofrequencies emitted by mobile telephones, by encouraging moderate use of these devices and giving preference to hand-free kits.

⁴⁶ "Exposure to radiofrequencies and children's health", June 2016, ANSES – <https://www.anses.fr/fr/system/files/AP2012SA0091Ra.pdf>.

Moreover, and from a general standpoint, especially 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 prior studies or a documented collection of the literature on the links between the exposure likely to arise from these technologies and the associated health impacts. These should take place in a timescale suited to the mobilisation of an expert appraisal,

Lastly, ANSES notes that the deployment of 5G technology is taking place at a time when society is being transformed by the emergence of new uses made possible by digital technologies and their widespread dissemination. One of the intentions of the developers of 5G technology is also to enable the emergence of other uses through more numerous and diversified connected objects.

Regardless of the technology, ANSES believes that the effects of this digital transformation taken as a whole, including those on the environment (direct and indirect energy consequences, footprint on air quality, soil contamination, water consumption and pollution, rare metal depletion, etc.) and those on the functioning of society (digital divide, equal access to services, risks of circulation of sensitive data, etc.) need to be better assessed. With this in mind, the Agency has undertaken an assessment of the impacts of digital use on the health of children and adolescents, which is separate from and complementary to the work it is carrying out on the health impact of exposure to electromagnetic waves.

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KEY WORDS

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.

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