BACKGROUND PAPER

ITU REGIONAL FORUM FOR EUROPE: 5G STRATEGIES, POLICIES, AND IMPLEMENTATION

IMPLEMENTING 5G FOR GOOD: DO EMFs MATTER?

Version 1.3

Acknowledgements: This report is a background-paper prepared by the ITU Office for Europe, Telecommunication Development Bureau (BDT), within the framework of the ITU Regional Initiative for Europe on "Broadband Infrastructure, Broadcasting and spectrum management". The paper has been developed with the support of the ITU Telecommunication Network and Spectrum Management Division and the ITU Human Capacity Building Division, and in coordination with the Radiocommunication Bureau (BR) and the Telecommunication Standardization Bureau (TSB). Substantive inputs to the report were provided by Dr. Haim Mazar (Madjar), ITU Consultant & ITU intersector coordinator on RF-EMF and co-rapporteur ITU-D Question 7/2, vice-chair ITU-R Study Group 5 (terrestrial services).

Note: Version 1.3 of this document is the final version which incorporates contributions from ITU-T Study Group 5.

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1. Introduction

1.1 The recent landscape

Human exposure to electromagnetic fields (EMF) from radio frequencies (RF) (RF-EMF) has been an element of concern and dispute among the public in some countries for decades, despite the broad availability of international scientific recommendations. As a result of public pressure, or previously existing standards, some countries have limit values that are more restrictive[1] than international recommendations which can lead to delays in antenna deployment, thereby increasing people's concerns of appearance of antennas and generating higher costs for society.

The recent Covid-19 pandemic and the related spread of misinformation around fifth generation (5G) has exacerbated this trend and, fueled by social media, has caused systematic incidents across a variety of countries. Some countries have even reported up to 100 incidents in the first half of 2020, including the burning or destruction of several antenna masts as well as harassment of telecom technicians.

In the context of 5G infrastructure roll-out and ensuring the safety of existing infrastructure and continuity of services, the recent increase in incidents poses a significant risk to deployment of next generation networks and to the operability of existing networks. This risk becomes even more important when considering that telecommunication networks have played a fundamental part in securing countries' resilience during the covid-19 crisis. It is therefore in the interest of the international community to provide clarity on how to address this increasingly relevant issue.

1.2 Purpose of the paper

This paper does not pretend to offer a definitive solution on the RF-EMF topic, nor convince the public of the reliability of international standards and recommendations. It seeks instead to provide countries with a review of relevant scientific evidence and an outline of the main contemporary challenges relating to RF-EMF, that would require coordinated action and communication at the national, regional and international level.

Managing compliance with human exposure limits for EMFs is a significant health and safety issue for regulators, service providers and wireless equipment suppliers. There is a large variation among countries on the regulations and the specific implementation measures for protecting the general public and workers from RF-EMF originating from transmitters. However, **there is no scientific reason to use different exposure limits in different countries,** suggesting that there is a tension between policymaking and pressure from public concern in this field.

Compliance and monitoring activities on human exposure limits for EMF are quite widely undertaken by regulators around the world, involving service providers and wireless equipment suppliers, although these activities differ in scale and scope. In general, **all these undertakings commonly and consistently show low-levels of exposure** in public areas from mobile network antennas, and that the **levels do not change significantly over time nor differ between countries, and are similar regardless of whether the international or more restrictive RF-EMF limits are adopted**[2,3].

5G is the fifth generation of mobile networks, a significant evolution of the fourth generation (4G) long-term evolution (LTE) networks which is using radio frequencies partially similar to those used in

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1 There are also some countries that retain more restrictive limits that predate the international limits.

2 Public exposure to radiofrequency electromagnetic fields in everyday microenvironments: An updated systematic review for Europe, Jalilian et al., Environmental Research, 176(108517), September 2019.

3 Comparative international analysis of radiofrequency exposure surveys of mobile communication radio base stations, Rowley et al., Journal of Exposure Science and Environmental Epidemiology, 22(3):304–315, May/June 2012.

previous generation networks. 5G has been designed to meet the extensive growth in data and connectivity of today's modern society, and tomorrow's innovations, just as previous generation technologies have supported economic growth and development in the past. To ensure the same level of safety in mobile communications, already existing RF-EMF standards and recommendations, for the existing frequency bands which are not technology-specific, must therefore be applied to 5G.

This report is based on scientific-data and references to recent deliverables from the International Telecommunication Union (ITU), the World Health Organisation (WHO), the International Commission on non-Ionizing Radiation Protection (ICNIRP) and the Institute of Electrical and Electronic Engineers (IEEE). By starting with a broad review of ITU Recommendations, Reports and conferences or workshops outcomes, this background-paper reviews the existing scientific recommendations in light of 5G, and addresses the main points of public concern about the deployment of 5G for good. The report therefore asks and addresses the question 'do EMFs Matter?' in the context of the deployment of 5G mobile networks.

2. Review of ITU Recommendations, Reports and Conferences divided by sectors

2.1 ITU Secretariat

2.1.1 Context to RF-EMF

The International Telecommunication Union is active in the field of RF-EMF across all its three sectors: the Telecommunication Standardization Sector (ITU-T), the Radiocommunication Sector (ITU-R) and the Telecommunication Development Sector (ITU-D). ITU-T and ITU-D studies are performed in the framework of Questions, while ITU-R Working Parties advance deliverables, not necessarily via Questions.

2.1.2 ITU Plenipotentiary Conference Resolution 176

At the ITU Plenipotentiary Conference (PP) in Guadalajara, Mexico, held in 2010, Member States have issued Resolution 176 (which was revised in Dubai, 2018) on 'Measurement and assessment concerns related to human exposure to electromagnetic fields'.

The PP Resolution 176 provides the ITU framework on EMF.

· Resolution 176 *resolves to instruct the Directors of the three Bureaux*:

1. to collect and disseminate information concerning exposure to EMF, including on EMF measurement methodologies, in order to assist national administrations, particularly in developing countries, to develop appropriate national regulations;
2. to work closely with all relevant organizations in the implementation of this resolution, as well as Resolution 72 (Rev. Hammamet, 2016) and Resolution 62 (Rev. Buenos Aires, 2017), in order to continue and enhance the technical assistance provided to Member States.

· Resolution 176 *Instructs the ITU-D Director, in collaboration with the Directors of the ITU-R and the ITU-T*

1. to conduct regional or international seminars and workshops in order to identify the needs of developing countries and build human capacity in regard to measurement of EMF related to human exposure to these fields;
2. to encourage Member States in the various regions to cooperate in sharing expertise and resources and identify a focal point or regional cooperation mechanism, including if required a regional centre, so as to assist all Member States in the region in measurement and training;
3. to encourage relevant organizations to continue undertaking necessary scientific studies to investigate possible health effects of EMF radiation on the human body;
4. to formulate necessary measures and guidelines in order to help mitigate possible health effects of EMF radiation on the human body;
5. to encourage Member States to conduct periodic reviews to ensure that ITU recommendations and other relevant international standards related to the exposure to EMF are followed.

· Resolution 176 *Instructs the ITU-T Director in collaboration with the Directors of the ITU-R and the ITU-D* to participate in the Electromagnetic Field Project, conducted by WHO, as part of collaborative efforts with other international organizations to encourage the development of international standards for EMF exposure.

2.2 ITU-T

2.2.1 Context to RF-EMF

The ITU Telecommunication Standardization Sector develops international standards known as ITU-T Recommendations which act as defining elements in the global infrastructure of information and communication technologies (ICTs). Standards are critical to the interoperability of ICTs and enable global communications by ensuring that countries' ICT networks and devices are speaking the same language. ITU-T Study Group 5 'Environment, climate change and circular economy' is very active on RF-EMF.

The ITU-T mandate for EMF is enshrined in the World Telecommunications Standardisation Assembly 2016 (WTSA-16) Resolution 72 (Rev. Hammamet, 2016) 'Measurement and assessment concerns related to human exposure to EMF':

resolves

to invite ITU-T, in particular Study Group 5, to expand and continue its work and support in this domain, including, but not limited to:

i) publishing and disseminating its technical reports, as well as developing ITU-T Recommendations to address these issues;

ii) developing, promoting and disseminating information and training resources related to this topic through the organization of training programmes, workshops, forums and seminars for regulators, operators and any interested stakeholders from developing countries;

iii) continuing to cooperate and collaborate with other organizations working on this topic and to leverage their work, in particular with a view to assisting the developing countries in the establishment of standards and in monitoring compliance with these standards, especially on telecommunication installations and terminals;

iv) cooperating on these issues with ITU-R Study Groups 1 and 6, and with Study Group 2 of the ITU Telecommunication Development Sector (ITU-D) in the framework of ITU-D Question 7/2;

v) strengthening coordination and cooperation with WHO in the EMF project so that any publications relating to human exposure to EMF are circulated to Member States as soon as they are issued,

instructs the Director of the Telecommunication Standardization Bureau, in close collaboration with the Directors of the other two Bureaux

within the available financial resources,

1 to support the development of reports identifying the needs of developing countries on the issue of assessing human exposure to EMF, and to submit the reports as soon as possible to ITU-T Study Group 5 for its consideration and action in accordance with its mandate;

2 to regularly update the ITU-T portal on EMF activities including, but not limited to, the ITU EMF Guide, links to websites, and flyers;

3 to hold workshops in developing countries with presentations and training on the use of equipment employed in assessing human exposure to RF energy;

4 to extend support for developing countries while they establish their regional centres equipped with test benches for continuous monitoring of EMF levels, especially in selected areas where the public has concerns, and transparently provide the data to the general public […];

5 to report to the next world telecommunication standardization assembly on measures taken to implement this resolution,

2.2.2 ITU-T Study Group 5 Question 3/5

ITU-T EMF activities are achieved in Study Group 5 Question 3/5: "Human exposure to electromagnetic fields (EMFs) from information and communication technologies (ICTs)".

2.2.3 ITU-T resources relating to EMF and 5G

Table 1: ITU-T Recommendations[4]

N°	Label	Title
1)	K.52	Guidance on complying with limits for human exposure to EMF
2)	K.61	Guidance on measurement and numerical prediction of EMF for compliance with human exposure limits for telecommunication installations
3)	K.70	Mitigation techniques to limit human exposure to EMFs in the vicinity of radiocommunication stations
4)	K.83	Monitoring of electromagnetic field levels
5)	K.90	Evaluation techniques and working procedures for compliance with exposure limits of network operator personnel to power-frequency EMF
6)	K.91	Guidance for assessment, evaluation and monitoring of human exposure to radio frequency EMF
7)	K.100	Measurement of radio frequency EMF to determine compliance with human exposure limits when a base station is put into service
8)	K.113	Generation of radiofrequency electromagnetic field level maps
9)	K.121	Guidance on the Environmental Management for Electromagnetic Radiation from Radiocommunication Base Stations
10)	K.122	Exposure levels in close proximity of radiocommunication antennas
11)	K.145	Assessment and management of compliance with radio frequency electromagnetic field exposure limits for workers at radiocommunication sites and facilities

[4] The EMF recommendations appear at ITU-T K. series

Table 2: ITU-T Supplements[5]

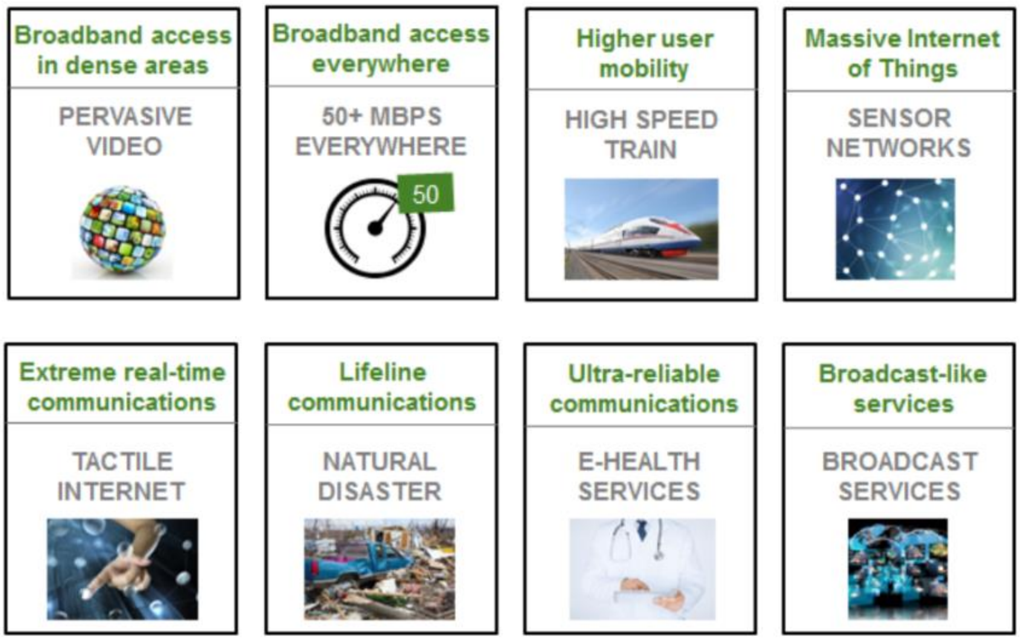
N°	Label	Title
1)	K Suppl. 1	ITU-T K.91 - Guide on electromagnetic fields and health
2)	K Suppl. 4	ITU-T K.91 - Electromagnetic field considerations in smart sustainable cities
3)	K Suppl. 9	**5G** technology and human exposure to radiofrequency EMF
4)	K Suppl. 13	Radiofrequency electromagnetic field (RF-EMF) exposure levels from mobile and portable devices during different conditions of use
5)	K Suppl. 14	The impact of RF-EMF exposure limits stricter than the ICNIRP or IEEE guidelines on 4G and **5G** mobile network deployment
6)	K Suppl. 16	Electromagnetic field compliance assessments for **5G** wireless networks
7)	K Suppl. 19	Electromagnetic field (EMF) strength inside underground railway trains
8)	K Suppl. 20	ITU-T K.91 – Supplement on radiofrequency exposure evaluation around underground base stations

2.2.4 ITU-T detailing the characteristics of 5G emissions

Future mobile communications will be increasingly based on 5G. The deployment of fifth generation (5G) will see the evolution and expansion of existing fourth generation (4G) networks and the introduction of new radio access networks in millimetre wavebands. As a result of the use of much higher frequency ranges (in parallel to the existing one), the number of base stations antennas will substantially increase. These networks will include a range of installations including smaller cell deployments and advanced antenna technologies. Massive multiple input multiple output (MaMIMO) antennas will allow the use of very narrow beams that will direct RF-EMF signals towards the user with a potential reduction of the surrounding exposure level different from that of current systems. The number of wireless devices will dramatically increase. New technology allows for the use of more efficient systems that require lower communication signal levels. The following (Fig. 1 in K Suppl. 9) details main usages for 5G networks.

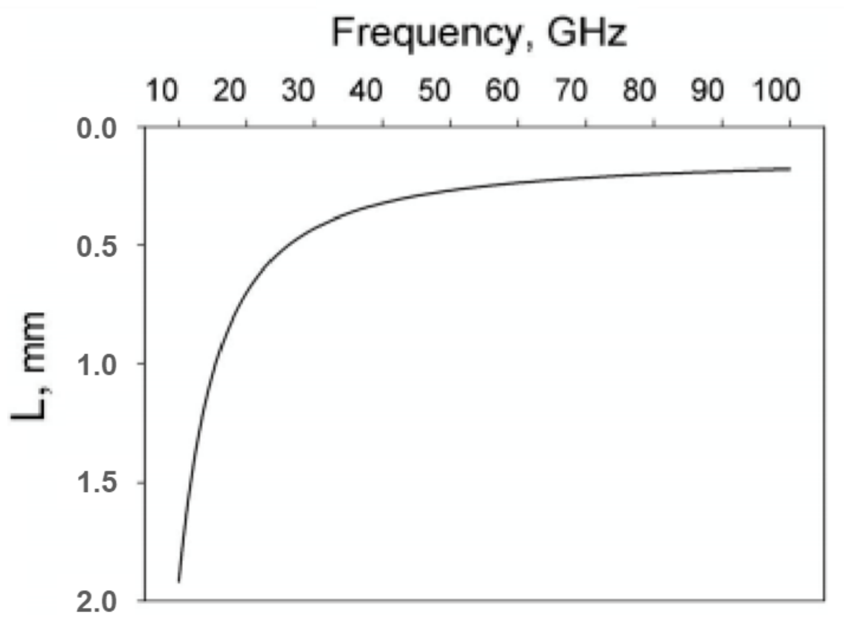
5 Supplements to ITU-T K-series Recommendations appear at K supplements

Figure 1 Main usage for 5G networks, to enhance future mobile communications



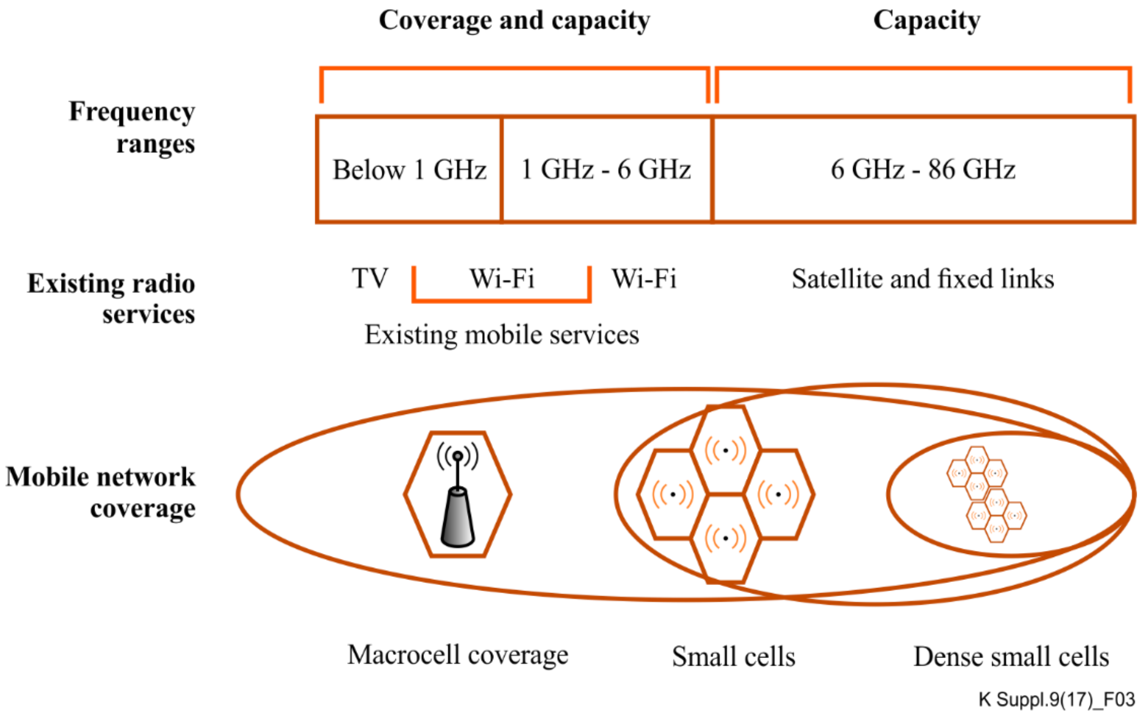
The increased spectrum also includes the millimetre waveband (mmWave) above 30 GHz (in fact the 26GHz band is considered in this way too); The mmWave frequencies provide localized coverage as they mainly operate over short line of sight distances. At mmWave frequencies, RF energy is absorbed superficially by the body, mostly by the skin. Some studies are already underway using these mmWave exposures. The mmWave frequencies will be used in conjunction with increased small cell deployments. There are fewer biological studies on frequencies above 24 GHz. The mmWaves are mostly absorbed in outer skin layers; see Figure 2, adapted from Alekseev et al. 2018 and Figure 5 penetration depth becomes shallower in 5G higher RF.

Figure 2 mmWaves are mostly absorbed in outer skin layers



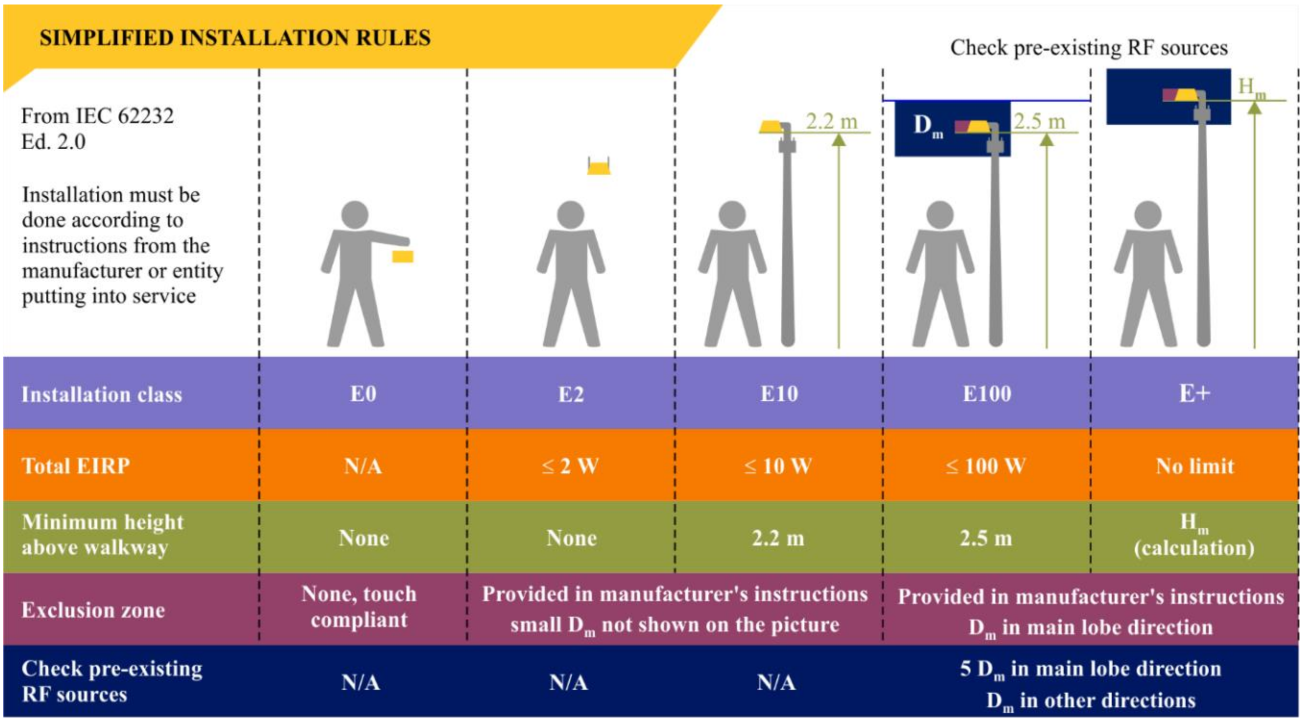
The following (Fig. 3 in K Suppl. 9)– details Frequency band allocation.

Figure 3 Frequency band allocation



The following Figure (Fig. 7 in K Suppl. 9 and Fig. 11 K Supp. 16) details simplified installation rules for base station equipment:

Figure 4 EMF compliance assessments for 5G wireless networks



K Suppl.9(17)_F07

The lowest power devices can be installed with the minimum of design constraints. Touch compliant equipment (installation class E0), such as residential small cells, can be sited anywhere, much like wireless access points. For higher power sites, manufacturers' guidelines, minimum height requirements (Hm) and exclusion zones (Dm) must be considered.

2.2.5 ITU-T detailing the characteristics of 5G emissions

On 5G those are the International Electrotechnical Commission (IEC)-
Standards:

- IEC/IEEE 62209-1528 (2020): Measurement procedure for the assessment of specific absorption rate of human exposure to radio frequency fields from hand-held and body-worn wireless communication devices - Part 1528: Human models, instrumentation and procedures (Frequency range of 4 MHz to 10 GHz)
- IEC 62232 (2017): Determination of RF field strength, power density and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure
- IEC TR62630 (2010): Guidance for evaluating exposure from multiple electromagnetic sources
- IEC TR63170 (2018): Measurement procedure for the evaluation of power density related to human exposure to radio frequency fields from wireless communication devices operating between 6 GHz and 100 GHz
- IEC/IEEE 62704-1 (2017): Determining the peak spatial-average specific absorption rate (SAR) in the human body from wireless communications devices, 30 MHz to 6 GHz - Part 1: General requirements for using the finite difference time-domain (FDTD) method for SAR calculations
- IEC/IEEE 62704-2 (2017): Determining the peak spatial-average specific absorption rate (SAR) in the human body from wireless communications devices, 30 MHz to 6 GHz - Part 2: Specific

requirements for finite difference time domain (FDTD) modelling of exposure from vehicle mounted antennas

- IEC/IEEE 62704-3 (2017): Determining the peak spatial-average specific absorption rate (SAR) in the human body from wireless communications devices, 30 MHz to 6 GHz - Part 3: Specific requirements for using the finite difference time domain (FDTD) method for SAR calculations of mobile phones
- IEC/IEEE 62704-4 (2020): Determining the peak spatial-average specific absorption rate (SAR) in the human body from wireless communication devices, 30 MHz to 6 GHz - Part 4: General requirements for using the finite element method for SAR calculations

Ongoing:

- IEC / IEEE 63195-1:Measurement procedure for the assessment of power density of human exposure to radio frequency fields from wireless devices operating in close proximity to the head and body – Frequency range of 6 GHz to 300 GHz, expected in Aug. 2021
- IEC/ IEEE 63195-2: Determining the power density of the electromagnetic field associated with human exposure to wireless devices operating in close proximity to the head and body using computational techniques, 6 GHz to 300 GHz, expected in Aug. 2021

2.3 ITU-R

2.3.1 Context to RF-EMF

The ITU Radiocommunication Sector (ITU-R) plays a vital role in the global management of the RF spectrum in demand from a large and growing number of services such as fixed, mobile, broadcasting, satellite, amateur, space research, emergency telecommunications, meteorology, global positioning systems, environmental monitoring and communication services. The Radiocommunication Sector has a decisive impact on establishing technical requirements for measurements of RF-EMF as well as identifying spectrum for next generation networks in the field of International Mobile Communications (IMT)[6].

Based on the ISCG website (under the General Secretariat) interesector mapping-tables, those are ITU-R Working Parties (WPs) that are related to ITU-D Q7/2 on EMF: 1A, 1C, 4A, 5A, 5B, 5C, 5D, 6A and 7B. In the framework of their Study Groups, those WPs settle the emission parameters that determine RF-EMF exposure levels, such as maximal power and maximal transmitter antenna gain, power-control. Based on Resolution Resolution 176, the most relevant WPs to study 5G RF-EMF are:

- WP 1C '*Spectrum monitoring*' implements the title of Resolution 176 '**Measurement** and assessment concerns related to human exposure to electromagnetic fields'.
- WP 5D '***IMT** Systems*' manages the overall radio system aspects of IMT systems;

2.3.2 ITU-R resources relating to EMF and 5G

EMF Measurement activities are accomplished in Study Group 1 via Question 239/1 'EMF measurements to assess human exposure'; 239/1 is directly founded on the Plenipotentiary Conference Resolution 176 (Rev. Dubai, 2018) and resulted in Report ITU-R SM.2452 'EMF field measurements to assess human exposure'; enclosed SM.2452 Table of Content.

In addition, ITU-R has developed the Handbook on Spectrum Monitoring which is highly relevant as it identifies methodologies to measure EMF. Section 5.6 specifies 'Non-ionizing radiation measurements'.

[6] IMT encompasses IMT-2000, IMT-Advanced and IMT-2020, as specified in Resolution ITU-R 56-2. In this ITU Report 5G and IMT-2020 are interchanged.

2.3.3 ITU-R WRC-19 Identification of IMT frequency bands

Future mobile communications will deploy more IMT/5G; see Figure 1.

Following the 2020 edition of the ITU Radio Regulations (RR) published on 15 September 2020 and the proposed revision of Recommendation ITU-R M.1036 that is currently discussed within ITU-R, the following frequency bands are identified in the ITU RR to deploy IMT.

Table 3: ITU RR 2020 Footnotes identifying the band for IMT

Band	Footnotes identifying the band for IMT		
	Region 1	**Region 2**	**Region 3**
450-470 MHz	**5.286AA**		
470–698 MHz	**-**	**5.295, 5.308A**	**5.296A**
694/698–960 MHz	**5.317A**	**5.317A**	**5.313A, 5.317A**
1 427–1 518 MHz	**5.341A, 5.346**	**5.341B**	**5.341C, 5.346A**
1 710–2 025 MHz	**5.384A, 5.388**		
2 110–2 200 MHz	**5.388**		
2 300–2 400 MHz	**5.384A**		
2 500–2 690 MHz	**5.384A**		
3 300–3 400 MHz	**5.429B**	**5.429D**	**5.429F**
3 400–3 600 MHz	**5.430A**	**5.431B**	**5.432A, 5.432B, 5.433A**
3 600–3 700 MHz	**-**	**5.434**	**-**
4 800–4 990 MHz	**5.441B**	**5.441A, 5.441B**	**5.441B**
24.25–27.5 GHz *	**5.532AB**		
37–43.5 GHz*	**5.550B**		
45.5–47 GHz*	**5.553A**	**5.553A**	**5.553A**
47.2–48.2 GHz*	**5.553B**	**5.553B**	**5.553B**
66–71 GHz*	**5.559AA**		

* revised at WRC-19

2.4 ITU-D

2.4.1 Context to RF-EMF

ITU-T and ITU-R are oriented on the technical and measurements aspects of 5G RF-EMF, while ITU-D concentrates on strategies and policies concerning human exposure.

The Telecommunication Development Sector role on EMF is enshrined in World Telecommunications Development Conference 2017 (WTDC-17) Resolution 62 (Rev. Buenos Aires, 2017) 'Assessment and measurement of human exposure to electromagnetic fields'. Resolution 62 (Rev. Buenos Aires, 2017) *instructs ITU-D Study Group 2* to cooperate with ITU-T Study Group 5 and ITU-R Study Groups 1, 4, 5 and 6, in order to achieve the following goals:

i) collaborate with ITU-T Study Group 5 in particular to update the mobile EMF guide application relating to human exposure to EMF and the guidance on its implementation, as a matter of high priority;

ii) contribute to the organization of seminars, workshops or training on the subject of EMF;

iii) ensure wide dissemination of ITU publications and literature on EMF issues;

iv) contribute to preparation of the guide on the use of ITU-T publications on electromagnetic compatibility and safety and on measurement methodologies, the need for measurements to be performed by a "qualified and certified radio engineer or technician" and the criteria for this "qualified radio engineer or technician", as well as system specifications;

v) continue to cooperate with the World Health Organization (WHO), the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the Institute of Electrical and Electronics Engineers (IEEE) and other relevant international organizations with regard to awareness and dissemination of information to the membership and the public.

Main ITU-D EMF activities are achieved in Study Group 2 Question 7/2 'Strategies and policies concerning human exposure to electromagnetic fields'. The ITU-D Regulatory & market environment, Broadband Series Exploring the Value And Economic Valuation Of Spectrum is relevant. The following Table details the ITU-D resources relating to EMF and 5G.

At October 2020 meeting of Q 7/2, this text was adopted: "Administrations are encouraged to follow the ICNIRP Guidelines or IEEE Standard, or limits set by their own experts. The best practice for Administrations that choose to use international RF-EMF exposure limits is to limit the exposure levels to the thresholds specified in ICNIRP (2020) Guidelines."

2.4.2 ITU-D resources relating to EMF and 5G

The following Table details the resources.

Table 4: ITU-D resources relating to EMF and 5G

N°	Deliverable	Label	Title
1)	WTDC-17	Resolution 62 (Rev. Buenos Aires, 2017)[7]	Assessment and measurement of human exposure to electromagnetic fields
2)	Question 7/2	Final Report to WTDC-2017[8]	Strategies and policies concerning human exposure to electromagnetic fields
3)	Question 7/2	Draft Report to WTDC-2021[9]	Policies, Guidelines, Regulations and Assessments of Human Exposure to RF-EMF
4)	ITU indicators	24th Edition/July 2020[10]	Mobile-cellular subscriptions (billions) and world-average cellular-penetration per 100 inhabitants

[7] See section 2.4.1 Context to RF-EMF

[8] See Final Report WTDC-17 Buenos Aires, Argentina, 9-20 October 2017

[9] See ITU-D Document 2/REP/23 (Annex 1)

[10] See Figure 14 Global mobile-cellular telephone subscriptions and rate

3. References to relevant international organizations/ standardization bodies

3.1 Context to RF-EMF

The following two Figures (source, Akimasa Hirata[11]) portray the power absorption in biological tissues: how by increasing frequency, the penetration depth becomes shallower. Above 6 GHz, skin surface heating is dominant, and the specific absorption rate (SAR) enters less distance.

Figure 5 penetration depth becomes shallower in 5G higher RF

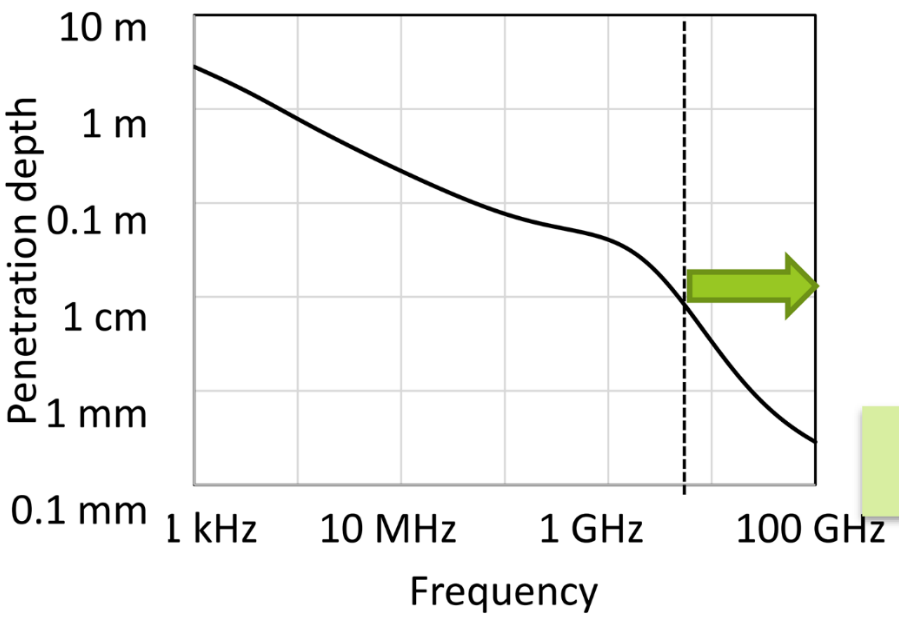
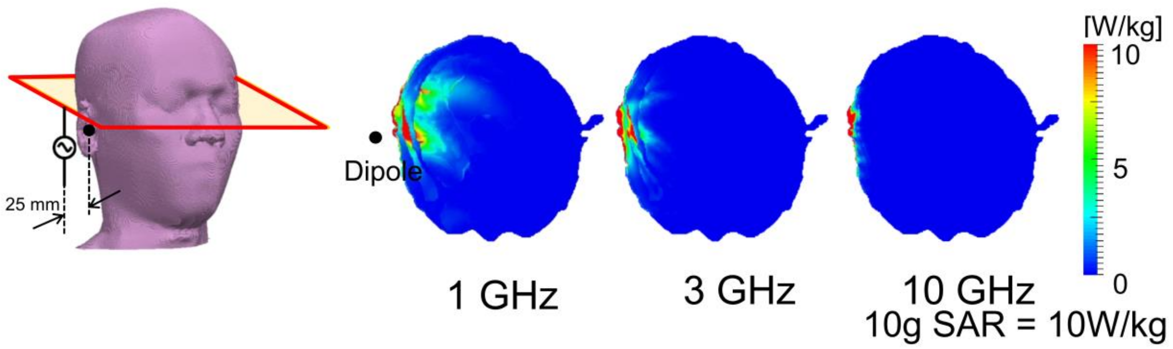


Figure 6 Measured power absorption in biological tissues



Two international bodies produce exposure guidelines on RF EMF. Many countries currently adhere to the guidelines recommended by[12]:

[11] Keynote-speaker to the EMC Europe 2020 plenary open-session 23 September 2020 'Human Exposure Standards and Compliance Assessment– 5G and Beyond'

[12] See WHO- What are the International exposure Guidelines? 27 February 2020

1 The International Commission on Non-Ionizing Radiation Protection (ICNIRP) and,
2 The Institute of Electrical and Electronics Engineers (IEEE), through the International Committee on Electromagnetic Safety

These guidelines are not technology-specific. They cover radiofrequencies up to 300 GHz, including the frequencies under discussion for 5G.

The ICNIRP has just revised its ICNIRP 1998 "ICNIRP Guidelines for Limiting Exposure to Time-varying Electric, Magnetic and Electromagnetic Fields (up to 300 GHz)". Following an extensive public consultation process in which the ITU provided 32 comments as an ITU inter-sectoral response, the final ICNIRP guidelines were published in March 2020. The IEEE has also published in October 2019 C95.1-2019 "IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 0 Hz to 300 GHz"; an update to IEEE C95.1-2005.

3.2 WHO

3.2.1 Context to RF-EMF

WHO works worldwide to promote health, keep the world safe, and serve the vulnerable. On the research and advocacy side, WHO is a fundamental point of reference for the international community when it comes to discussing EMF, as Administrations follow WHO recommendations. Although WHO doesn't produce technical standards for EMF, it works with the ICNIRP and IEEE by reviewing academic research and issuing reports for communication and aimed at raising objective awareness among the public around this topic.

The World Health Organization (WHO) definition (1948) of "health": a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.

Relevant WHO links: WHO Radiation Health Topics, WHO EMF website, National regulations on exposure to EMF, WHO Fact sheets on mobile phones and base stations.

As part of its mission to provide clear information on the topic of EMF, the WHO published on 27 February 2020 '5G mobile networks and health' information site addressing and responding to a number of questions related to fifth generation networks in relation to health risks. Please see below some extract from this site. The following sections 3.2.2, 3.2.3 and 3.2.4 appear at https://www.who.int/news-room/q-a-detail/5g-mobile-networks-and-health .

3.2.2 Exposure level from 5G infrastructure?

Currently, exposure from 5G infrastructures at around 3.5 GHz is similar to that from existing mobile phone base stations. With the use of multiple beams from 5G antennas, exposure could be more variable as a function of location of the users and their usage. Given that the 5G technology is currently at an early stage of deployment, the extent of any change in exposure to radiofrequency fields is still being under investigation.

3.2.3 What are the potential health risks from 5G?

1 To date, and after much research performed, no adverse health effect has been causally linked with exposure to wireless technologies. Health-related conclusions are drawn from studies performed across the entire radio spectrum but, so far, only a few studies have been carried out at the frequencies to be used by 5G.
2 Tissue heating is the main mechanism of interaction between radiofrequency fields and the human body. Radiofrequency exposure levels from current technologies result in negligible temperature rise in the human body.

3 As the frequency increases, there is less penetration into the body tissues and absorption of the energy becomes more confined to the surface of the body (skin and eye). Provided that the overall exposure remains below international guidelines, no consequences for public health are anticipated.

3.2.4 What is WHO doing?

1 WHO is conducting a health risk assessment from exposure to radiofrequencies, covering the entire radiofrequency range, including 5G, to be published by 2022.
2 WHO will review scientific evidence related to potential health risks from 5G exposure as the new technology is deployed, and as more public health-related data become available.
3 WHO established the International EMF Project in 1996. The project investigates the health impact of exposure to electric and magnetic fields in the frequency range 0-300 GHz and advises national authorities on EMF radiation protection.
4 WHO advocates for further research into the possible long-term health impacts of all aspects of mobile-telecommunications. The Organization identifies and promotes related research priorities. It also develops public information materials and promotes dialogue among scientists, governments, and the public to increase understanding around health and mobile communications.

3.3 ICNIRP and its Guidelines

3.3.1 Context to RF-EMF

ICNIRP aims to protect people and the environment against adverse effects of non-ionizing radiation (NIR). To this end, ICNIRP develops and disseminates science-based advice on limiting exposure to NIR. Experts from different countries and disciplines such as biology, epidemiology, medicine, physics, and chemistry, work together with and within ICNIRP to assess the risk of NIR exposure and provide exposure guidance. ICNIRP experts base their advice on scientific publications about biological effects and action mechanisms of radiation, for the whole NIR frequency range. ICNIRP's protection advice is formulated in its Guidelines, Reviews and Statements, which are publicly and freely available online. ICNIRP also organizes workshops to inform about current scientific knowledge and to provide an opportunity to advance the dialogue on NIR protection.

ICNIRP Guidelines have been widely adopted in standards and regulations around the world; where national limits do not exist, or if they do not cover the frequencies of interest, then ICNIRP limits should be used. The following are the ICNIRP Guidelines relevant to 5G:

1 ICNIRP (1998): Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz) replaced by;
2 ICNIRP (2020): Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz).

Compared to ICNIRP (1998), ICNIRP (2020) provide a better biological rationale, better dosimetry, more details, more complexity, more accuracy and are overall future-proof. ICNIRP (2020) Guidelines were developed by identifying scientific data on effects of exposure, determining effects considered both adverse to humans and scientifically substantiated, identifying minimum exposure level needed to produce harm, and finally by applying reduction factors and larger for general public than for workers. This results in exposure restrictions with a large margin of safety.

The scientific basis: there is no evidence for cancer, electro hypersensitivity, infertility or other health effects. The identified adverse health effects are only whole body temperature increase above 1 °C and tissue temperature above 41 °C.

Physics and Temperature: different quantities used to estimate temperature depending on frequency and duration of exposure. For example, for local exposures: absorbed energy rate, such as SAR at lower frequencies, power-density at higher frequencies.

3.3.2 ICNIRP (2020) Tables and Figures

As this background-paper refers only to 5G (IMT) frequencies between 450 MHz – 71 GHz[13], the following Tables will indicate most relevant rows and columns, to focus on the significant values of 5G RF-EMF. This section details the ICNIRP (2020) Tables (1, 5 and 6) that are most relevant to this Report. The re-elaborated Figures depict the values. Underlines indicate the significant parameter.

Table 5: (ICNIRP 2020 Table 1) Quantities and corresponding SI units used in these guidelines

Quantity	**Symbol***	**Unit**
Absorbed energy density	U_{ab}	joule per square meter (J m^{-2})
Incident energy density	U_{inc}	joule per square meter (J m^{-2})
Plane-wave equivalent incident energy density	U_{eq}	joule per square meter (J m^{-2})
Absorbed power density	S_{ab}	watt per square meter (W m^{-2})
Incident power density	S_{inc}	watt per square meter (W m^{-2})
Plane-wave equivalent incident power density	S_{eq}	watt per square meter (W m^{-2})
Specific energy absorption	SA	joule per kilogram (J kg^{-1})
Specific energy absorption rate	SAR	watt per kilogram (W kg^{-1})
Frequency	f	hertz (Hz)
Time	t	second (s)

* *Italicized* symbols represent variables; quantities are described in scalar form because the direction is not used to derive the basic restrictions or reference levels.

The ICNIRP Tables and Figures quantify and depict how the exposure depends on the transmitted frequency.

ICNIRP (2020) Tables 5 and 6 detail reference levels for exposure, averaged, to EMF 100 kHz–300 GHz (unperturbed rms values). See enclosed these two Tables.

The following Table specifies that the RF-EMF limits for the Occupational and General Public whole-body exposures increase between 400 – 2000 MHz and stay steady 2 – 300 GHz.

13 Also 71 GHz is still much lower frequency compared to ionizing radiation: frequencies above 2,900 THz ($2{,}900\times10^{12}$ Hz, $2{,}900\times10^{3}$ GHz).

Table 6: (ICNIRP 2020 Table 5) Reference levels for exposure, averaged over 30 minutes and the whole body, to electromagnetic fields from 100 kHz to 300 GHz (unperturbed rms values)

Exposure scenario	Frequency range	Incident power density; S_{inc} (W m^{-2})
Occupational	>400 – 2000 MHz	$f_M/40$
	>2 – 300 GHz	50
General Public	>400 – 2000 MHz	$f_M/200$
	>2 – 300 GHz	10

Notes:

1. 'NA' signifies 'not applicable' and does not need to be taken into account when determining compliance.
2. f_M is frequency in MHz.
3. S_{inc} to be averaged over 30 minutes, over the whole-body space. Temporal and spatial averaging of each of E_{inc} and H_{inc} must be conducted by averaging over the relevant square values (see Eqn. 8 in Appendix A for details).
5. For frequencies of >30 MHz to 2 GHz: (a) within the far-field zone: compliance is demonstrated if either S_{inc}, E_{inc} or H_{inc}, does not exceed the above reference level values (only one is required); S_{eq} may be substituted for S_{inc}; (b) within the radiative near-field zone, compliance is demonstrated if either S_{inc}, or both E_{inc} and H_{inc}, does not exceed the above reference level values; and (c) within the reactive near-field zone: compliance is demonstrated if both E_{inc} and H_{inc} do not exceed the above reference level values; S_{inc} cannot be used to demonstrate compliance, and so basic restrictions must be assessed.
6. For frequencies of >2 GHz to 300 GHz: (a) within the far-field zone: compliance is demonstrated if S_{inc} does not exceed the above reference level values; S_{eq} may be substituted for S_{inc}; (b) within the radiative near-field zone, compliance is demonstrated if S_{inc} does not exceed the above reference level values; and (c) within the reactive near-field zone, reference levels cannot be used to determine compliance, and so basic restrictions must be assessed.

The following Table specifies that the RF-EMF limits for the Occupational and General Public local exposures increase (as in the Table above) from 400 – 2000 MHz, stay steady 2 – 6 GHz, and decrease 6 –300 GHz.

Table 7: (ICNIRP 2020 Table 6) Reference levels for local exposure, averaged over 6 minutes, to electromagnetic fields from 100 kHz to 300 GHz (unperturbed rms values)

Exposure scenario	Frequency range	Incident power density; S_{inc} (W m^{-2})
Occupational	>400 – 2000 MHz	$0.29f_M^{0.86}$
	>2 – 6 GHz	200
	>6 – <300 GHz	$275/f_G^{0.177}$
	300 GHz	100
General Public	>400 – 2000 MHz	$0.058f_M^{0.86}$
	>2 – 6 GHz	40
	>6 – 300 GHz	$55/f_G^{0.177}$
	300 GHz	20

Notes: (Underlined values are most relevant to 5G)

1. 'NA' signifies 'not applicable' and does not need to be taken into account when determining compliance.
2. f_M is frequency in MHz; f_G is frequency in GHz.
3. S_{inc} to be averaged over 6 minutes, and where spatial averaging is specified in Notes 6-7, over the relevant projected body space. Temporal and spatial averaging of each of E_{inc} and H_{inc} must be conducted by averaging over the relevant square values (see Eqn. 8 in Appendix A for details).
5. For frequencies of >30 MHz to 6 GHz: (a) within the far-field zone, compliance is demonstrated if one of peak spatial S_{inc}, E_{inc} or H_{inc}, over the projected whole-body space, does not exceed the above reference level values (only one is required); S_{eq} may be substituted for S_{inc}; (b) within the radiative near-field zone, compliance is demonstrated if either peak spatial S_{inc}, or both peak spatial E_{inc} and H_{inc}, over the projected whole-body space, does not exceed the above reference level values; and (c) within the reactive near-field zone: compliance is demonstrated if both E_{inc} and H_{inc} do not exceed the above reference level values; S_{inc} cannot be used to demonstrate compliance; for frequencies >2 GHz, reference levels cannot be used to determine compliance, and so basic restrictions must be assessed.
6. For frequencies of >6 GHz to 300 GHz: (a) within the far-field zone, compliance is demonstrated if S_{inc}, averaged over a square 4-cm^2 projected body surface space, does not exceed the above reference level values; S_{eq} may be substituted for S_{inc}; (b) within the radiative near-field zone, compliance is demonstrated if S_{inc}, averaged over a square 4-cm^2 projected body surface space, does not exceed the above reference level values; and (c) within the reactive near-field zone, reference levels cannot be used to determine compliance, and so basic restrictions must be assessed.
7. For frequencies of >30 GHz to 300 GHz, exposure averaged over a square 1-cm^2 projected body surface space must not exceed twice that of the square 4-cm^2 restrictions.

The following Table details the ICNIRP (2020) Basic Restrictions.

Table 8: ICNIRP (2020) Guidelines in brief- Basic Restrictions

Parameter	Frequency range	ΔT	Spatial averaging	Temporal averaging	Health effect level	Reduction factor	Workers	Reduction factor	General public
Core ΔT	100 kHz–300 GHz	1° C	WBA (whole body average)	30 min	4 W/kg	10	0.4 W/kg	50	0.08 W/kg
Local ΔT (Head & Torso)	100 kHz–6 GHz	2° C	10 g	6 min	20 W/kg	2	10 W/kg	10	2 W/kg
Local ΔT (Limbs)		5° C			40 W/kg		20 W/kg		4 W/kg
Local ΔT (Head & Torso, Limbs)	>6– 300 GHz 30– 300 GHz	5° C	4 cm^2 1 cm^2		200 W/m^2 400 W/m^2		100 W/m^2 200 W/m^2		20 W/m^2 40 W/m^2

The following two figures[14] depict the differences between the 2020 **field-strength** and **power-density** exposure levels of **occupational** and **general-public** exposure, averaged over **30 min** and the **whole body**. The behaviour of the exposures (increase with RF and then steady) are well illustrated. The power-density ratio of 5 in ICNIRP (2020) Table 5 (e.g. at 30 – 400 MHz, Watts ratio 50/10) results in V/M ratio 61.0/27.7 = 2.2 ~ √5.

[14] Four different ICNIRP (2020) figures appear in the 'Differences 2020 1998 Guidelines'.

Figure 7 - Comparing ICNIRP (2020) Table 5, power-density for occupational and general-public exposures 30 MHz– 300GHz, averaged over 30 min and the whole body

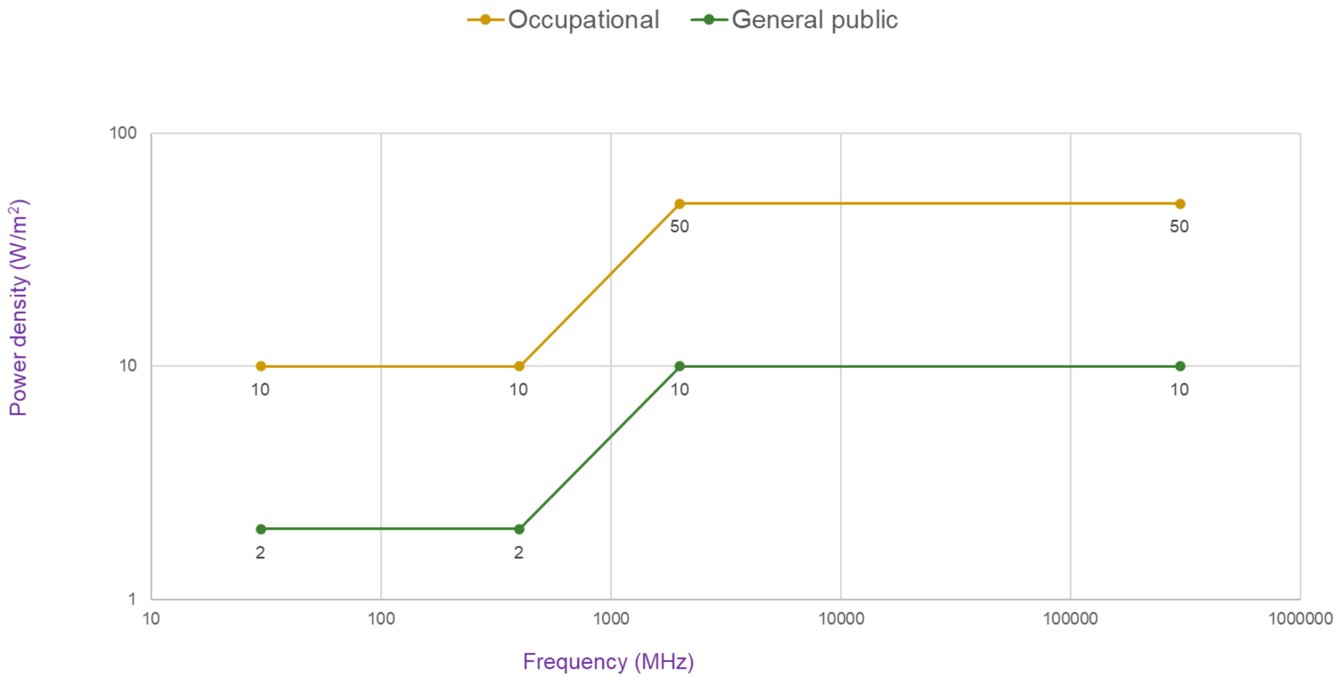
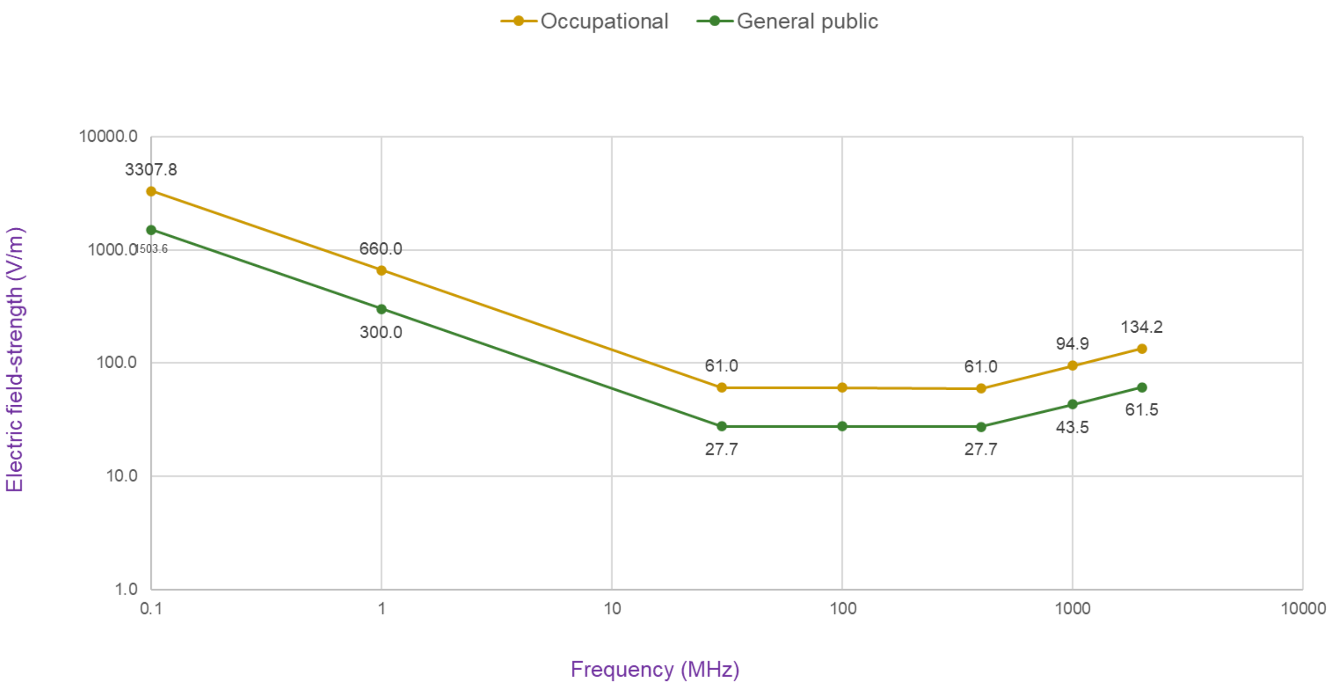
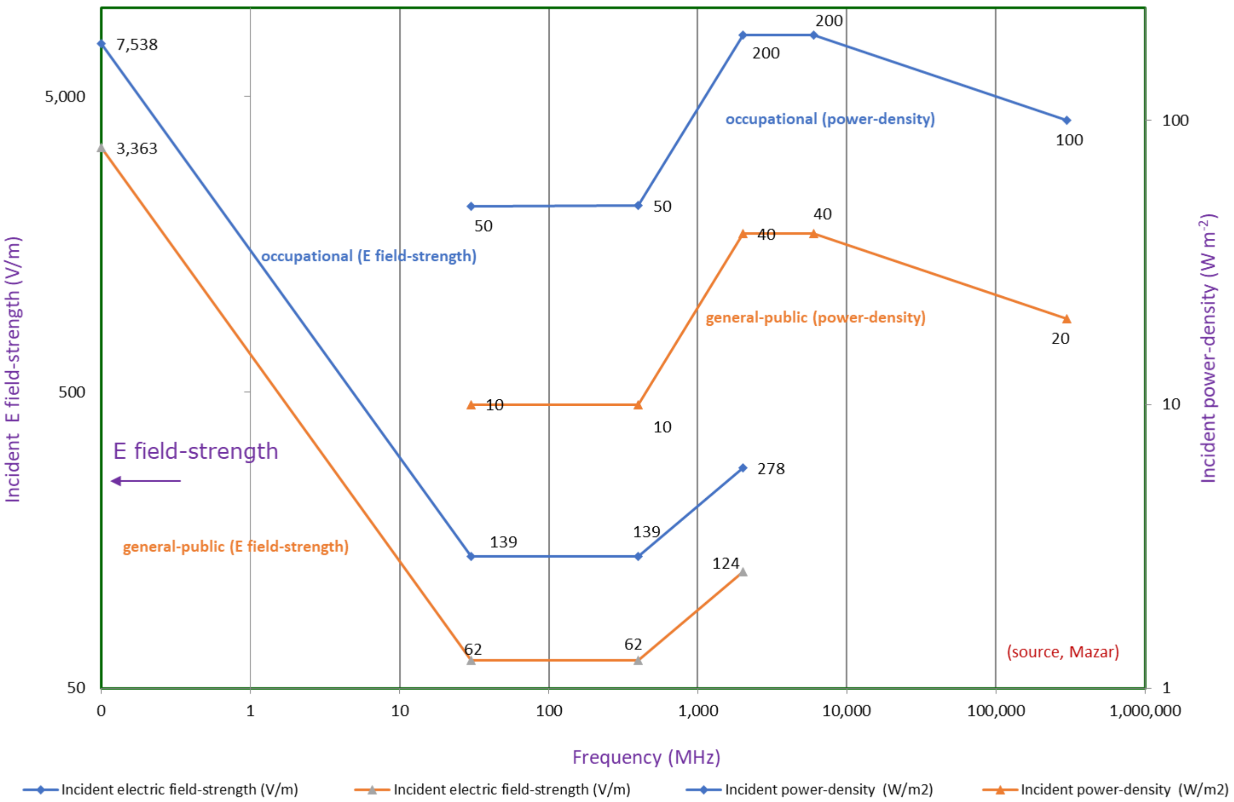


Figure 8 - Comparing ICNIRP (2020) Table 5, field-strength for occupational and general-public exposure, 0.1 MHz–2 000 MHz, averaged over 30 minutes and the whole-body



The following Figure summarises the local exposure limits. Administrations may use it together with Table 7: (ICNIRP 2020 Table 6**)** Reference levels for local exposure, averaged over 6 minutes, to electromagnetic fields from 100 kHz to 300 GHz (unperturbed rms values).

Figure 9 Comparing occupational and general-public exposures in ICNIRP (2020) Table 6, incident electric field-strength and power-density; local exposure, averaged over 6 minutes



Note: The unit of the figure's left-side is electric field-strength V/m, and the right-side is power density W/m².

3.4 IEEE and its standard IEEE C95.1 (2019)

3.4.1 Context to RF-EMF

IEEE is the world's largest technical professional organization dedicated to advancing technology. With an active portfolio of nearly 1,300 standards and projects under development, IEEE is a leading developer of industry standards in a broad range of technologies that drive the functionality, capabilities, and interoperability. The International Committee on Electromagnetic Safety (ICES) operating under the rules and oversight of the IEEE Standards Association (SA), is responsible for the development of standards for the safe use of electromagnetic energy by developing exposure limits and product compliance assessment standards in the range of 0 Hz to 300 GHz. ICES develops EMF exposure limits (Technical Committee 95), and product Compliance Assessment Standards (TC34).

IEEE/ICES TC95 develops RF-EMF exposure standards for the safe use of electromagnetic energy in the range of 0 Hz to 300 GHz relative to the potential hazards of **exposure of humans**[15], volatile materials and explosive devices. Such standards are based on established adverse health effects. C95.1-2019 is the 'IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz'

3.4.2 C95.1-2019 reference levels: safety factors applying 100 kHz- 6 GHz; Thermal Effects[16]

- Whole body averaged (WBA)
  Behavioural effects in animals over many frequencies, threshold at 4 W/kg, before dividing by:
  10x - 0.4 W/kg for upper tier (controlled environment)
  50x - 0.08 W/kg for lower tier (general public)
- Localized exposure (averaged in 10 g),
  Cataract observed in rabbits, threshold at 100 W/kg, before dividing by:
  10x - 10 W/kg for upper tier
  50x - 2 W/kg for lower tier
- SAR is averaged over 30 min for WBA exposure and 6 min for local exposure
- Epithelial power density through body surface is averaged over 6 min[17].

15 Including methods for the assessment of human exposure to such fields, and safety levels for human exposure to electric, magnetic and EMF.

16 See IEEE C95.1 (2019) p. 57 and consolidation in EMF, New ICNIRP Guidelines and IEEE C95.1-2019 Standard: 3-4 December, 2019; p. 6. ITU-D mission TA No 2713-2019, Warsaw; Mazar.

17 The averaging time is 30 minutes for whole body RF exposure, and 6 minutes for local exposure; this is different from IEEE C95.1-2005.

3.4.3 Dosimetric Reference Limits and Exposure Reference Level[18]

The following two Tables specify Dosimetric Reference Limits (DRLs) below and above 6 GHz; no continuity at 6 GHz in exposure metrics, but maintains continuity in thermal protection. Note that unrestricted environments SAR 2 (W/kg) is identical to SAR values in IEEE C95.1-2005, ICNIRP (1998) and (2020)[19].

Table 9: IEEE C95.1 (2019) (Table 5) – Dosimetric Reference Limits, DRLs (100 kHz to 6 GHz)

Conditions Persons in	**unrestricted environments SAR (W/kg)[a]**	**restricted environments SAR (W/kg)[a]**
Whole-body exposure	0.08	0.4
Local exposure[b] (head and torso)	2	10
Local exposure[b] (limbs and pinnae)	4	20

[a] SAR is averaged over 30 min for whole-body exposure and 6 min for local exposure.
[b] Averaged over any 10 g of tissue (defined as a tissue volume in the shape of a cube). The averaging volume of 10 g of tissue would be represented as a 10 cm3 cube (approximately 2.15 cm per side)

Table 10: IEEE C95.1 (2019) (Table 6) – DRLs (6 GHz to 300 GHz)

Conditions	**Epithelial power density (W/m^2)[a,b,c]**	
	Persons in unrestricted Environments	**Persons permitted in restricted environments**
Body surface	20	100

[a] Epithelial power density through body surface is averaged over 6 min.
[b] Averaged over any 4 cm^2 of body surface at frequencies between 6 GHz and 300 GHz (defined as area in the shape of a square at surface of the body).
[c] Small exposed areas above 30 GHz: If the exposed area on the body surface is small (< 1 cm^2 as defined by −3 dB contours relative to the peak exposure), the epithelial power density is allowed to exceed the DRL values of Table 6 by a factor of 2, with an averaging area of 1 cm22 (defined as area in the shape of a square at the body surface).

The following Table details Exposure Reference Level (ERLs) for whole-body exposure of persons in unrestricted environments, averaging time 30 minutes.

Table 11: IEEE C95.1 (2019) (Table 7) – Exposure Reference Level, ERLs (100 kHz–300GHz)

Frequency range (MHz)	**Electric field Strength (*E*)[a,b,c] (V/m)**	**Magnetic field strength (*H*)[a,b,c] (A/m)**	**Power density (*S*)[a,b,c] (W/m^2)**	
			S_E	S_H
0.1 to 1.34	614	$16.3/f_M$	1000	$100\ 000/f_M^2$
1.34 to 30	$823.8/f_M$		$1800/f_M^2$	
30 to 100	27.5	$158.3/f_M^{1.668}$	2	$9\ 400\ 000/f_M^{3.336}$
100 to 400		0.0729	2	
400 to 2000			$f_M/200$	

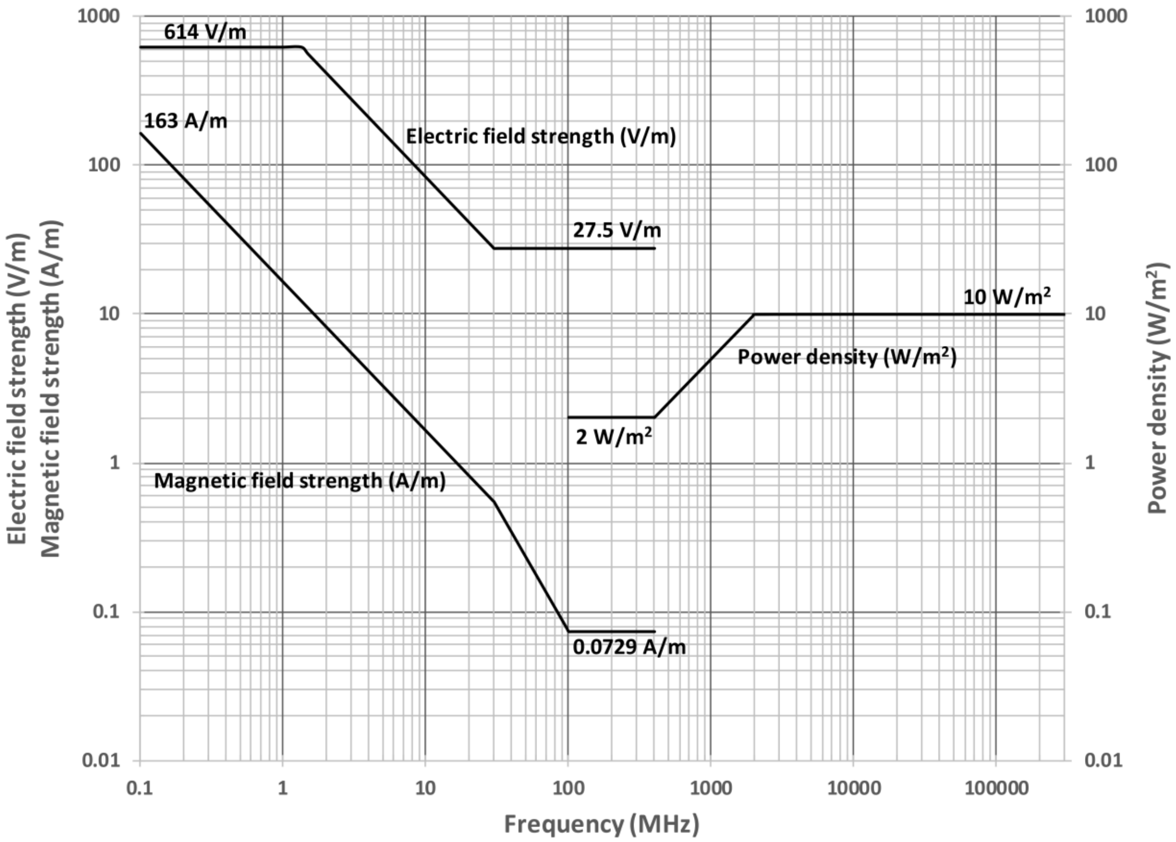
18 See IEEE C95.1 (2019), Tables 5 to 8, Figures 3 and 4.
19 Therefore, 2 (W/kg) is the SAR value that Admirations may apply to test 5G cellular equipment.

2000 to 300 000		10

Note—S_E and S_H are plane-wave-equivalent power density values, based on electric or magnetic field strength respectively, and are commonly used as a convenient comparison with ERLs at higher frequencies and are sometimes displayed on commonly used instruments.
[a] For exposures that are uniform over the dimensions of the body, such as certain far-field plane-wave exposures, the exposure field strengths and power densities are compared with the ERLs in IEEE 95.1 Table 7. For more typical non-uniform exposures, the mean values of the exposure fields, as obtained by spatially averaging the plane-wave-equivalent power densities or the squares of the field strengths, are compared with the ERLs in Table 7.
[b] f_M is the frequency in MHz.
[c] The *E*, *H*, and *S* values are those rms values unperturbed by the presence of the body.

The following Figure depicts IEEE C95.1 (2019) Figure 3—Graphical representations of the ERLs in Table 7 of IEEE standard, electric and magnetic fields and plane-wave-equivalent power density—Persons in **unrestricted** environments.

Figure 10 (C95.1 (2019) Figure 3) EMFs and power density—unrestricted environments



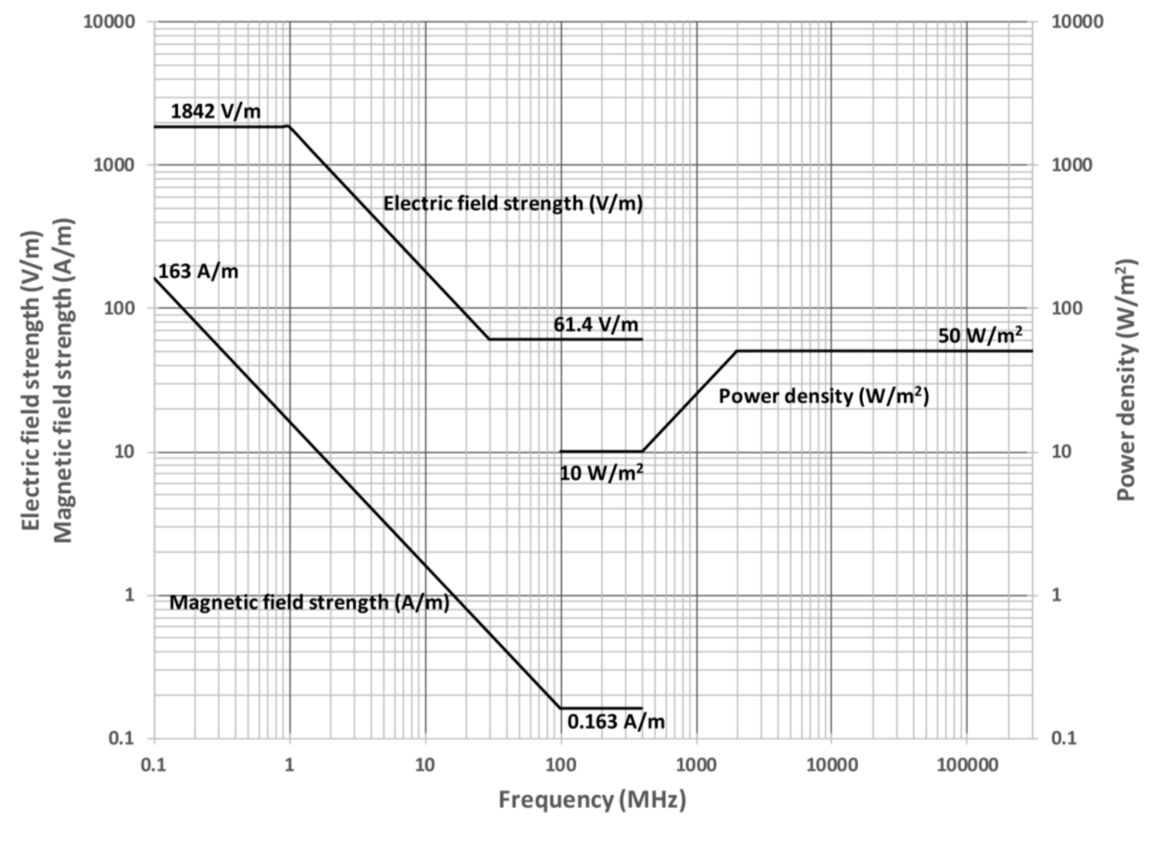
Important to note, not mentioned at the IEEE 95.1 (2019) standard, that at frequencies below 30 MHz, the wave-length is longer than 10 m. There is no resonance with the human body (shorter than 2 m.). We are not an obstacle to the signal, and there is low absorption of the RF energy from the body.
The following Table details IEEE C95.1 (2019) Table 8—ERLs for whole-body exposure of persons permitted in restricted environments (100 kHz to 300 GHz), the averaging time is 30 minutes.

Table 12: IEEE C95.1 (2019) (Table 8) – ERLs in restricted environments (100 kHz to 300 GHz)

Frequency range (MHz)	Electric field Strength $(E)^{a,b,c}$ (V/m)	Magnetic field strength $(H)^{a,b,c}$ (A/m)	Power density $(S)^{a,b,c}$ (W/m^2)	
			S_E	S_H
0.1 to 1.0	1842	16.3/f_M	9 000	100 000 f_M^2
1.0 to 30	1842/f_M		9000 / f_M^2	
30 to 100	61.4		10	
100 to 400		0.163	10	
400 to 2000			f_M/40	
2000 to 300 000			50	

The following Figure depicts IEEE C95.1 (2019) (Fig. 4): Graphical representations of the ERLs in IEEE (Table 8) for electric and magnetic fields and plane-wave-equivalent power density – Persons permitted in **restricted** environments.

Figure 11 (C95.1 2019 Fig. 4) EMFs and power density—restricted environments



3.5 Comparing ICNIRP (1998), IEEE 95-1 (2019) and ICNIRP (2020)

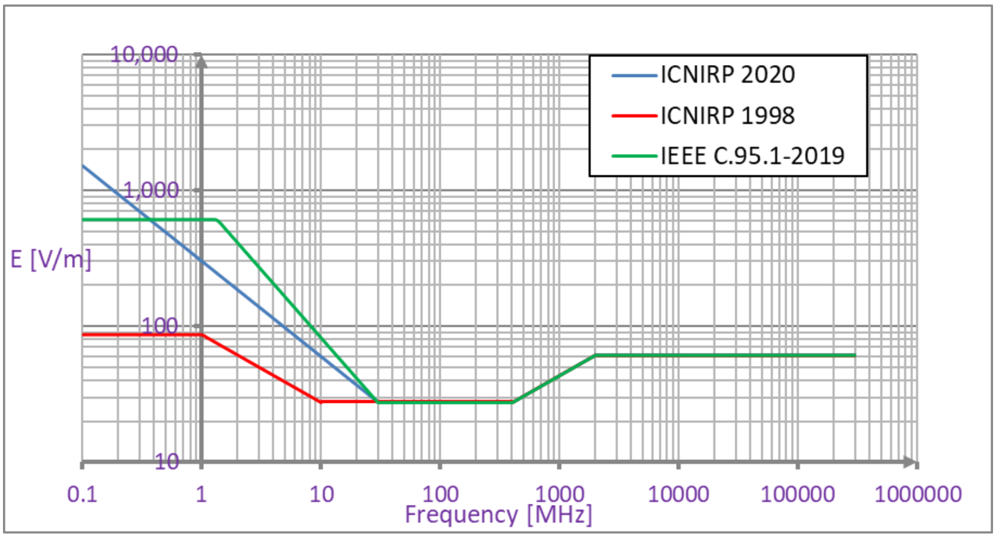
3.5.1 Context to RF-EMF

IEEE C95.1 (2019) and ICNIRP (2020) Guidelines to limit exposures drom base-stations and handsets are largely harmonized in regard to limit values but the terminology differs in some areas; see the next two sections.

3.5.2 Comparison for exposure from base stations

The following Figure is retrieved from the presentation of Dr. Lewicki Fryderyk at the ITU Regional Symposium for Europe and CIS on Spectrum Management and Broadcasting 02 July 2020, Electromagnetic Fields and 5G Implementation;. Note: reference-levels of ICNIRP (2020) stop electric-field at RF above 2 000 MHz, and the Figure refers to V/m till 300 GHz.

Figure 12 ICNIRP (1998), IEEE 95.1 (2019) and ICNIRP (2020); reference levels, general public



Note: some Administrations prefer to monitor and measure electric field-strength V/m and not power density W/m²

3.5.3 Limits applicable to 5G cellular handsets

The general, thepublic receives the highest exposure to EMF from handheld devices such as mobile phones, which deposit most of the radio frequency (RF) energy in the brain and surrounding tissues. Though they still remain within internationally recommended limits, typical exposures to the brain from handsets are several orders of magnitude higher than those from mobile-phone base stations on rooftops or from terrestrial television and radio stations.

As far as exposure levels are concerned, a distinction is made between the fixed radiating transmitters of the base stations and the portable handsets. The far-field[20] exposure relative to power density (or field-strength) limits from fixed wireless stations is practical to analyse (easily simulated and measured). On the other hand, the handset is used in proximity to the user's body, meaning that the

20 Based on Rec ITU-T K.61, Rec K.91 defines far-field as "that region of the field of an antenna where the angular field distribution is essentially independent of the distance from the antenna. In the far-field region, the field has predominantly a plane-wave character, i.e. locally uniform distribution of electric field strength and magnetic field strength in planes transverse to the direction of propagation".

body in conjunction with the handset design have a strong impact on the RF-EMF in the near-field[21]. The Specific Absorption Rate (SAR)[22] relates to the internal electric-field and by extension the temperature rise due to the EMF, mainly defines the threshold limits for sources used close to the body, including handsets and notebooks.

Manufacturers follow international compliance testing standards, to ensure that when tested the device operating at maximum power will comply with relevant international or national limits. The handset is working in full output power in the most conservative conditions (obstacles or long distance to base station), and in minimum output power in the best connection conditions (line of sight propagation and close to the base station). The maximum SAR level for different mobile phones varies according to technology and many other factors, for example, SAR is also influenced by technical parameters such as the antenna used and its placement within the device.

Table 4 of ICNIRP (1998) stated 'Localized SAR (head and trunk) from 10 MHz to 10 GHz, localized SAR (head and trunk) from 100 kHz to 10 GHz **2.0 (W kg^{-1})**, averaged over 10 g tissue.
Table 8: ICNIRP (2020) Guidelines in brief- Basic Restrictions in this Document also specifies for head and torso, at 100 kHz−6 GHz, ΔT 2°C, spatial averaging 10 g, temporal averaging 6 min, health-effect level 20 W/kg, reduction-factor 2, workers 10 W/kg, reduction-factor 10, general-public **2 W/kg.** The ICNIRP (2020) local SAR restrictions (100 kHz to 6 GHz) are given in ICNIRP (2020) Table 2 'Basic restrictions for electromagnetic field exposure from 100 kHz to 300 GHz, for averaging intervals ≥6 min'; the values are unchanged compared to ICNIRP (1998): **2.0 (W kg^{-1})**.
The IEEE C95.1 (2005) p. 78 stated 'The peak spatial average SAR values have been changed from 1.6 W/kg and 8 W/kg for exposure of the public and exposures in controlled environments to 2 W/kg and 10 W/kg, respectively. Similar sentence 'The peak spatial-average SAR (psSAR) values were changed in IEEE Std C95.1-2005 from 1.6 W/kg and 8 W/kg for exposure of the public and exposures in controlled environments to 2 W/kg and 10 W/kg, respectively.' appears in IEEE C95.1 (2019) p. 72. Therefore, the 1995 SAR level 1.6 W/kg was changed in 2005, and stays 2 W/kg in IEEE C95.1 (2019); see IEEE (2019) Table 5—DRLs (100 kHz to 6 GHz).
ICNIRP (2020) introduces a new basic restriction (S_{ab}, absorbed power density) from 6 to 300 GHz of 20 W/m^2 for the public; see ICNIRP (2020) Tables 1 and 2. Additional reference levels for local exposure averaged over 6 minutes are given in ICNIRP (2020) Table 6. Whether the basic restriction or the reference level should be used for compliance is determined by Notes 5 and 6 of ICNIRP (2020) Table 6; see the underlined Notes of Table 7: (ICNIRP 2020 Table 6) Reference levels for local exposure, averaged over 6 minutes, to electromagnetic fields from 100 kHz to 300 GHz (unperturbed rms values) in this Document. These new basic restrictions/reference levels are relevant for IMT 5G devices operating at higher frequencies.

In this Document Table 9: IEEE C95.1 (2019) (Table 5) – Dosimetric Reference Limits, DRLs (100 kHz to 6 GHz) specifies for common to ICNIRP and IEEE local-exposure (head and torso) **2 (W/kg)** for persons in unrestricted environments (general-public).

21 Based on Rec ITU-T K.52, Rec K.91 defines near-field as "the near-field region exists in the proximity to an antenna or other radiating structure in which the electric and magnetic fields do not have a substantially plane-wave character but vary considerably from point to point".

22 SAR is the time derivative of the incremental power absorbed by (dissipated in) an incremental mass; it is expressed in W/kg. See also Recommendation (Rec) ITU-T K.52.

4. Open issues directly and indirectly related to RF-EMF health hazards

4.1 Context to RF-EMF

Due to the perceived uncertainties, several national legislative bodies enacted precautionary measures with the intention of reducing exposure to EMF, for example by imposing limits more restrictive than limits of ICNIRP, or advise personal steps to reduce exposures. However, measurements show that typical exposure levels in public areas are not reduced by adopting more restrictive limits. In addition, the ICNIRP (2020) Guidelines say 'There is no evidence that additional precautionary measures will result in a benefit to the health'. There is evidence that reducing RF-EMF exposure limits may be associated with higher levels of public concern. The migration from GSM to 3G/UMTS is a way to reduce exposure to RF-EMF from devices, due to more efficient power control algorithms.

The national authority assigning frequencies, environment protection or public health authorities may be responsible for the compliance verification. The local planning authority and town councils may also be involved in the process. In order to demonstrate compliance, the applicant (transmitter operator) should provide relevant information to one or more authorities, increasing the difficulty of the bureaucratic process from the operator's perspective. Some authorities adopt predictive modelling, to calculate the exposure-ranges or compliance zone around the antenna.

Random sample measurement may be used to monitor RF-EMF levels around a transmitter, with priority given to areas of community interest (schools, hospitals, etc.), at the initiative of the authorities, or on request subsequently to concerns by general public. However, specific requirements for siting of base station in such locations are not supported by scientific evidence and, measurements consistently show low-levels of exposure in public areas from mobile network antennas.

Compliance with RF-EMF limits is important to regulators, service providers and wireless equipment suppliers. Populations are exposed to different sources of radiofrequency electromagnetic fields (RF-EMF), the levels of which are perceived to increase due to traffic growth, increased usage of data services, quality of service (QoS) requirements, network coverage and capacity extension, and the introduction of new technologies. Limitations to RF human exposure contain restrictions that are intended to assist those with responsibility for the safety of the general public and workers.

4.2 Open issues related to health hazards, directly related to the human hazards

Wireless communication use electromagnetic waves in RF ranges of the spectrum, which are of much lower frequencies compared to ionizing radiation[23], such as X-rays or Gamma-rays. As such, RF waves do not have enough energy to either break molecular bonds or even cause ionization of atoms in the human body; hence, their classification as Non-Ionizing Radiation (NIR). The instant heating capabilities of high-level RF-EMF exposure (e.g., microwave ovens) are well known. The question is whether there are some other enduring health effects at levels of exposure below the ICNIRP limit. While some studies have indicated the possibilities of non-thermal effect in living organism, they have never been substantiated.

ICNIRP guidelines are backed by WHO, and constitute the current scientific consensus. Some countries (and cities) adopt stricter measures (lower RF thresholds) which lead to severe restrictions the ability to deploy radio transmitters, that are at odds with those of the international community. Other limit proposals are based on arbitrary choice of reduction factors.

Parts of the public have remained concerned, on the basis that there exists no proof that ICNIRP threshold levels are safe, as they claim that not all possible health effects were studied. Though it is scientifically impossible to prove absolute safety (the null hypothesis) of any physical agent (ANSI/IEEE C95.1-2005[24]: p.2), as it is impossible to prove the negative, (i.e. that something does not exist), an analysis of the balance between cost and potential hazards is essential to inform policymakers.

As absolute proof does not logically exist, national regulators are placed under public pressure. To answer this dilemma, some countries apply the precautionary principle to restrict the human-hazards. The precautionary-approach and the “As Low As Reasonably Achievable” (ALARA) concept to the RF-EMF health risk management problem may replace the two-state risk management model (above/below the threshold), allowing the introduction of other factors. It is a trade-off balance between the remaining uncertainty (and the damage in the case that the worst-case turns true), versus implementing stricter requirements (resources and reduced quality of service) and other wider societal impacts[25].

As the choice between the two-state risk management model or the precautionary approach has indirect implications on society and the economy, it is important to involve all stakeholders in community awareness activities: government agencies, the private Internet sector, non-governmental organization, community groups and the general public.

23 Electromagnetic radiation at frequencies above the ultra-violet band are classified as “ionizing radiation”, because when incident on matter they have enough energy to effect changes in the atoms, by liberating ionizing electrons and thus altering their chemical bonds. Ionizing radiation occurs at frequencies above. 2,900 THz ($2{,}900\times10^{12}$ Hz). This frequency limit corresponds to a wavelength of about 103.4 nm; and minimum ionization energy of 12eV.

24 IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz.

25 Mobile Phone Use for Contacting Emergency Services in Life-threatening Circumstances, Wu et al., The Journal of Emergency Medicine, 52(3):291–298.e293, March 2012.

4.3 Social and economic risks, indirectly related to the human health hazards

Compared to 4G, 5G, especially at higher frequencies, will more heavily rely on small cells, meaning that a greater number of 5G base stations will be installed. If not addressed, this factor alone may cause a number of socio-economic hazards including:

- Spread of misinformation
- Delay in installing base stations (causing harm to operators and delay of service provision)
- Raising the economic cost for society
- Having an impact on the environment

Moreover, another element of 5G that may further create misunderstanding is the more intensive use of mmWaves. These frequencies have been used for decades for other wireless applications such as microwave communication, satellite and radar. In this regard, it should be clarified that 5G wireless networks are designed to be efficient: this means that both the network and device transmission power will be low, which means that levels of RF-EMF for mmWaves in a 5G environment will remain within the ICNIRP/IEEE exposure limits.

It is important to properly address these concerns, and to ensure the efficiency of wireless networks and maintain low RF-EMF levels through the evolution of the current networks and expansion of 5G wireless networks, which constitute the key infrastructure that will underpin a smarter information society.

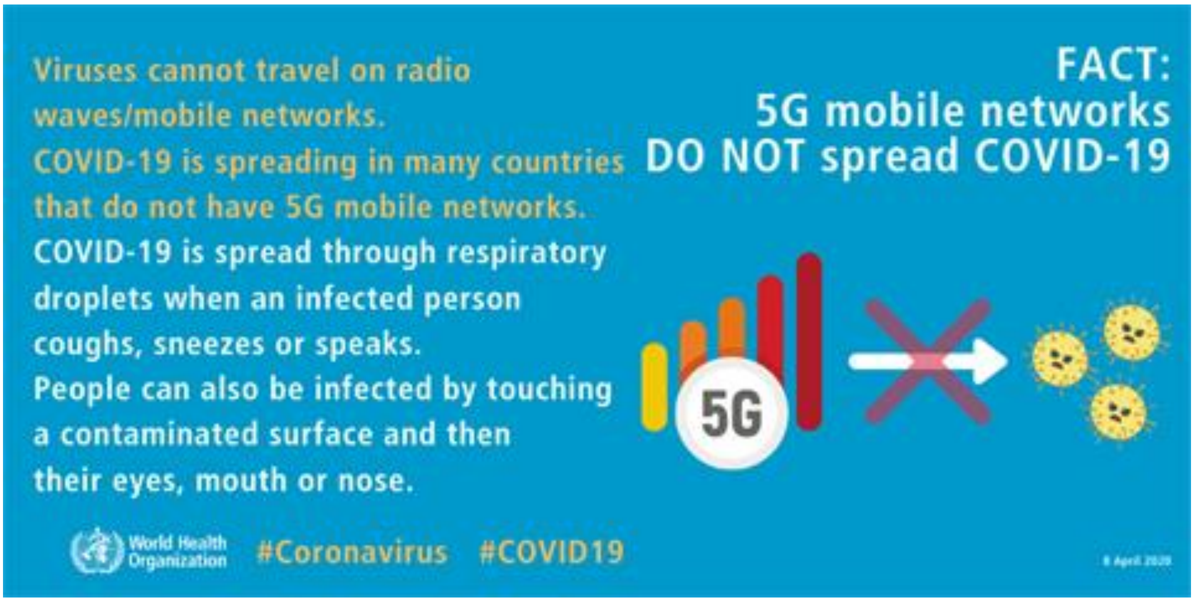
4.3.1 Misinformation

New technologies bring many benefits, but may also raise questions from the public in terms of exposure to RF EMF. It is important to address these questions and provide information on likely exposure. Public workshops and conferences are important.

With the introduction of new technologies and wireless applications, there may be a change (increase or decrease) in the overall level of radio signals, due to the fact that new transmitters rely on active beamforming. Overall, and based on the transition from previous wireless technologies, we can expect that overall exposure levels will remain similar and will be a small fraction of the international exposure limits. Tissue heating remains the only recognized and substantiated hazard of exposure to mmWave, based on scientific research to date. However, despite much research and communication efforts to resolve it, there is still some public concern about the possible harmfulness of RF-EMFs from mobile communication equipment.

Conferences and workshops are important to publish scientific-data on 5G and EMF. However, those who suffer from electrophobia and fear antenna masts will not be convinced by scientific evidence.

Figure 13 5G mobile networks DO NOT spread COVID-19



The WHO[26] makes clear that 'viruses cannot travel on radio waves/mobile networks' and that '5G mobile networks DO NOT spread COVID-19.' The ITU[27] highlighted the importance of 'trusted news and facts' stating 'As claims linking 5G technology and the spread of COVID-19 are mounting, ITU stands on the side of science and makes it clear that such claims have no scientific basis whatsoever.'

Responding to public concerns, Ofcom published on February 2020 the results of measurements of EMF exposures close to sixteen 5G-enabled mobile phone base stations showing RF-EMF levels at a total of 22 5G sites in 10 UK cities, including also measurements for 2G, 3G and 4G:

1. EMF exposure levels from 5G-enabled base stations remain at small fractions of the reference levels for public exposure in ICNIRP (1998) Guidelines (400–2,000 MHz) f (MHz)/200 (W/m^2), and 2–300 GHz 10 (W/m^2);
2. The highest level recorded being approximately 1.5% of the power-density reference level.
3. In all locations, the largest contribution to the measured levels comes from previous generations of mobile technology (2G, 3G, 4G);
4. The highest level observed in the band used for 5G was just 0.039% of the reference level.

4.3.2 Delays in installing base-stations

National regulations have a priority status in their countries; as influenced by social-economic-political factors, the values adopted in each country may vary. Restrictive exposure limits affect network planning. Co-location and MIMO increase the safety distance if theoretical maximum conditions are applied and restrict mast construction near buildings. Countries (e.g. Switzerland) reduce by 100 the power-density level and indirectly restrict the cellular base-station location[28]. A consequence of restrictive RF-EMF exposure limits enforces reduction in the Equivalent Isotropic Radiated Power (EIRP) (in order to reduce the RF-EMF exposure near the station) or to extend the distance of the mast from the public. Restrictive RF-EMF exposure limits may be addressed by additional cellular antennas or added RF Spectrum.

26 https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public/myth-busters#5g

27 https://www.itu.int/en/Pages/COVID-19/5g-covid-19-statement.aspx

28 Such limits are usually considered for each mobile system separately

It is important to have measurement methods in place, to assess the RF exposure from 5G base stations and survey that limits are met. Especially the use of Active Antenna Systems (AAS) requires for novel measurement approaches to cope with the varying and dynamic RF configuration of the 5G signal. First proposals have been published.[29] However, a widely accepted standardised approach is still missing.

4.3.3 Economic cost for society

Based on ITU-D 'Exploring the Value and Economic Valuation of Spectrum' Table 2, those are the socioeconomic and policy factors affecting the RF value:

1. Socioeconomic factors are demographics, population density, income distribution, economic level and growth rate, political stability, absence of corruption and rule of law;
2. Policy and regulation factors include the existence of an independent regulatory agency, favourable investment and customs laws, competition policy, infrastructure sharing, rules of protection of the public against electromagnetic waves, open access rules, technology neutrality, protection against interference, coverage obligations, spectrum caps, auction rules and bidding credits/set-asides, transparency, licensing framework and dispute-resolution mechanisms.

Restrictive RF-EMF exposure limits imply higher investments in infrastructures and base- stations. Restrictive RF-EMF exposure limits achieve the double negative outcome of increasing the need of more antennas and thereby creating additional public concern. In this context, studies show that restrictive limits risk doubling the investment required in the order of billions[30] and block the potential to use spectrum and address growing traffic requirements[31].

29 The Technical Report: Measurement Method for 5G (New Radio) NR Base Stations up to 6 GHz, published by the Federal Institute of Metrology, Switzerland.

30 An example of economic cost for society in Italy, which has 100 times stricter power-density than EMF ICNIRP/IEEE limits, namely 10 W/m^2 at frequencies 2 – 300 GHz for 30 min whole-body exposure; see ICNIRP (2020) Table 5 and IEEE (2019) Table 7. A study presented at the Italian Parliament argues that avoiding installations of 27,900 5G base-stations approximately requires in total € 4 billion additional costs.

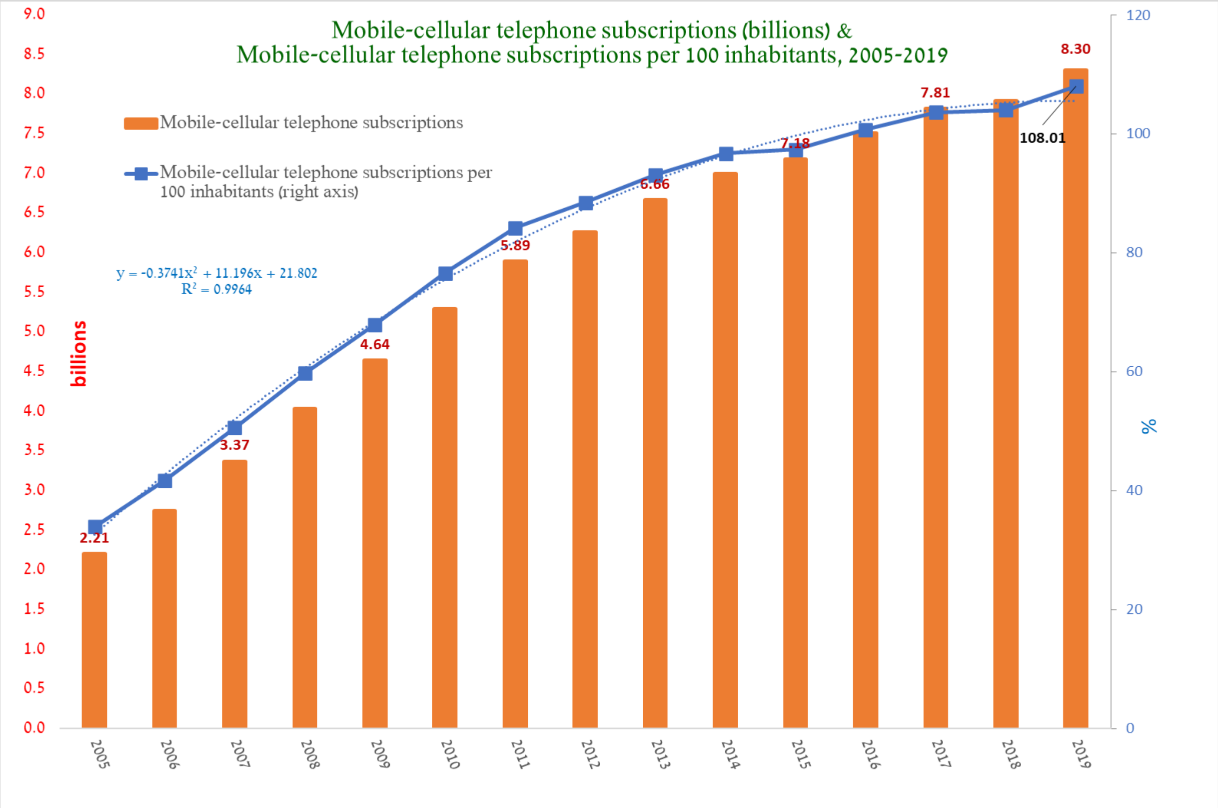
31 ITU-T K Suppl. 14 (09/2019) *The impact of RF-EMF exposure limits stricter than the ICNIRP or IEEE guidelines on 4G and 5G mobile network deployment*.

4.4 Number of base stations

The proliferation of cellular base stations and wireless fixed installations around the world, the public dislike of large antenna structures and the growing concern against RF-EMF exposure has led to constraining legislations and regulations to ensure protection of the public[32].

To provide evidence on the proliferation of cellular base stations around the world, based on ITU indicators, the following Figure depicts the mobile-cellular subscriptions (billions) and world-average cellular-penetration per 100 inhabitants, years 2005 to 2019. The 24th Edition/July 2020 indicates that there were 8.3 billion subscribers in 2019 (and 108 cellular telephone subscriptions per 100 inhabitants). As in average, roughly every 1,000 subscribers need one cellular mast[33], there are more than 8 million base stations around the world.

Figure 14 Global mobile-cellular telephone subscriptions and rate



Cellular capacity is limited by RF bandwidth, power and noise; adding RF bandwidth to base stations may decrease the number of base stations and the total RF-EMF exposure.

32 See H. Mazar, Radio Spectrum Management: Policies, Regulations, Standards and Techniques, Chichester, West Sussex: John Wiley & Sons, Ltd., 2016; Chapter 9 pp. 359–397.

33 See H. Mazar, Radio Spectrum Management: Chapter 9 Section 9.6.2.

5. ITU Initiatives and Opportunities

5.1 Human capacity building opportunities

As part of its Human Capacity Building operations, the ITU has developed a number of online and face-to-face trainings in the field of information and communication technologies targeting regulators and policymakers, technical and operational staff, as well as students and entrepreneurs.

With regards to EMF, the 2014 Spectrum Management Training Programme (SMTP) was edited by BDT, BR and ITU experts. Courses oriented to broaden the skills from different backgrounds (engineering, legal, economic, etc.), working in the field of spectrum-management (for example in a national regulatory authority, providers or operators of wireless communications). In particular, an advanced module 'Electro Magnetic Fields and Health", which is part of SMTP was prepared in April 2020, with the objective of providing a deeper understanding of this field. This SMTP module supports modern spectrum management students with spectrum engineering foundations, to calculate EMF contours around wireless base stations, using 3D propagation and antenna patterns modelling. The advanced Module provides specific training on:

- radio-waves;
- RF Spectrum and wireless communications;
- ITU Activities on EMF;
- WHO's views;
- non-ionizing radiation, physical quantities and units;
- biological effects;
- ICNIRP (2020) and IEEE (2019) EMF levels;
- EMF measurements around the world;
- demonstrating compliance and exposure zones;
- engineering: calculating safety-distances, far- and near-field;
- total exposures;
- policies and mitigation techniques to reduce human exposure;
- application example practical exercise and quiz, measurements of EMF and preparing for 5G;
- exposure assessment and societal-concerns.

More information about the course and about the ITU Academy can be found at hcbmail@itu.int.

5.2 ITU workshops, initiatives and recent events related to EMF

ITU is active in sharing knowledge and tools concerning assessment of human exposure to RF EMF.

1) ITU-T Workshop on Human Exposure to Electromagnetic Fields (EMFs):
The ITU together with the Ministry for Economic Development of Italy organized a workshop on Human Exposure to EMFs. The workshop was held on 9 May 2013 in Turin, Italy. Measurement concerns related to human exposure to EMF.

2) ITU Forum on "EMF - What does it really mean?"

At the invitation from the Dominican Institute for Telecommunications (INDOTEL), ITU-T organized a Forum that took place on 4 September 2014 in Santo Domingo. The Forum responds to WTSA-12 Resolution 72, to provide an overview of EMF issues to policy makers and other stakeholders. The Forum focused on Latin America, to identify few actions for ITU-T Study Group 5. The forum brought together leading specialists in the field, from top policy-makers to engineers, designers, planners, government officials, regulators, standards experts and others.

3) Electromagnetic Field Level and 5G Roll-out

The expert meeting on EMF and 5G Roll-out hold in Rome, Italy, from 2 to 3 November 2017. This meeting was organized by ITU BDT in cooperation with the Ministry of Economic Development of Italy, within the framework of the ITU Regional Initiative for Europe on Development of Broadband Access and Adoption of Broadband.

4) How safe is EMF?

ITU- T/R Forum & Training on With ICTs everywhere – How safe is EMF? Zanzibar, Tanzania, 10 April 2018.

5) 5G seminar in Hungary in July 2018

The 5G Implementation in Europe and CIS in the Regional Seminar on 5G Implementation in Europe and CIS: Strategies and Policies Enabling New Growth Opportunities. It was organized by ITU and hosted by National Media and Infocommunications Authority of Hungary from 3 to 5 July 2018, included an experts' knowledge exchange related to the work of the ITU-D two study groups, including EMF.

6) Modern policies, guidelines, regulations and assessments of human exposure to RF-EMF
ITU-D workshop on modern policies, guidelines, regulations and assessments of human exposure to RF-EMF, ITU, Geneva 10 Oct. 18, See workshop presentations at https://www.itu.int/en/ITU-D/Study-Groups/2018-2021/Pages/meetings/session-Q7-2-oct18.aspx

7) International Conference: EMF and the Future of Telecommunications
8) Three presentations in Warsaw[34]:
    a. 2017 ITU Workshop '5G, EMF & Health'; Warsaw, Poland, 5 December 2017
    b. ITU WRC-19, additional spectrum allocations for IMT-2020 (5G mobile), 3 Dec. 2019;
    c. EMF, new ICNIRP Guidelines and IEEE C95.1 (2019) Standard: differences and similarities, 4 Dec. 2019.
9) ITU-D and PRIDA Workshops

The pan-African program Policy and Regulation Initiative for Digital Africa (PRIDA) and ITU-D provided those two recent EMF work-shops:

    a. On-line English workshop RF Human Hazards 24 April 2020
    b. On-line French workshop RF Human Hazards 15 May 2020
10) ITU Regional Symposium for Europe and CIS on Spectrum Management and Broadcasting 02 July 2020, Electromagnetic Fields and 5G Implementation.
11) Safety and Environmental Concerns around Telecommunications Installations and Services in Uganda 11 August 2020
12) ITU Regional Forum for Europe 5G Strategies, Policies and Implementation.

This Forum, originally planned in Warsaw, Poland, at the kind invitation of the Ministry of Digital Affairs of Poland, takes place virtually from 22 to 23 October 2020. This Forum is organized within the framework of the ITU European Regional Initiative on Broadband Infrastructure, broadcasting and spectrum management adopted by the ITU World Telecommunication Development Conference 2017 (WTDC-17).

[34] ITU-D Europe Regional mission TA No 2713-2019

6. Conclusions

This background-paper reviews scientific evidence from ITU Recommendations, Reports, conferences, workshops and initiatives divided by three sectors. Moreover, the background paper refers to the relevant international organisations/standardisation bodies WHO, ICNIRP and IEEE. It details the revisions of IEEE (2019) and ICNIRP (2020) exposure levels, so Administrations may understand the complicated EMF Standard and Guidelines landscape. Administrations are encouraged to follow the RF-EMF limits set by the science-based ICNIRP and IEEE expert groups, or thresholds set by their own experts. It is strongly suggested to adopt harmonized international standards and EMF exposure limits. It should be mentioned that IEEE C95.1 (2019) standard and ICNIRP (2020) Guidelines are largely coherent. Moreover, this paper has discussed open questions relating to health hazards, finding that there is no scientific reason to adopt stricter RF-EMF limits in relation to 5G, although research continues to clarify the issue even further. This is particularly necessary in the context of potential socio/economic hazards relating to RF-EMF and 5G, that may materialize in the form of increased misinformation, delay in base station deployment, higher social costs for society or higher environmental impacts. Understanding the framework of the scientific base of the harmonized international limits assists legislation-bodies to trust on these limits.

ITU also recommends that administrations make reference to the existing technical documentation and the revised ICNIRP (2020) or IEEE (2019) Guidelines on EMF exposure limits in their transition to 5G. A science-based approach based on the explanation of RF-EMF in relation to 5G deployment should support clear information to address the concerns of the public, thereby preventing or limiting potential hazards outlined in this paper.

It is sensible to affirm that yes, discussing RF-EMF does indeed matter to countries' successful and smooth transition to 5G and better communication around the topic should be coordinated at national and international levels.

7. Annex: Abbreviations and acronyms

3D	Three Dimensional
2G	2nd Generation mobile technology
3G	3rd Generation mobile technology
4G	4th Generation mobile technology
5G	5th Generation mobile
BR	Basic Restriction
BS	Base Station
DRL	Dosimetry Reference Limit
EHS	Electromagnetic HyperSensitivity
EIRP	Equivalent Isotropic Radiated Power
EMF	ElectroMagnetic Field
EMR	ElectroMagnetic Radiation
ERL	Exposure Reference Level
ERP	Effective Radiated Power
FCC	Federal Communications Commission
Gbit/s	Giga bits per second
GPS	Global Positioning System
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ICT	Information and Communication Technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
IMT	International Mobile Telecommunications
ITU	International Telecommunication Union
LTE	Long-Term Evolution
MIMO	Multiple-Input and Multiple-Output
M2M	Machine-to-Machine
Mbit/s	Megabits per second
MPE	Maximum Permissible Exposure
NIR	Non-ionizing Radiation
PFD	Power Flux Density
RF	Radio Frequency
RR	Radio Regulations (ITU)
SAR	Specific Absorption Rate
SI	International System of Units
SMTP	Spectrum Management Training Programme
WHO	World Health Organization
WP	Working Party