International EMF Exposure Guidelines

Explaining the 2020 RF-EMF exposure guidelines published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP)

October 2021

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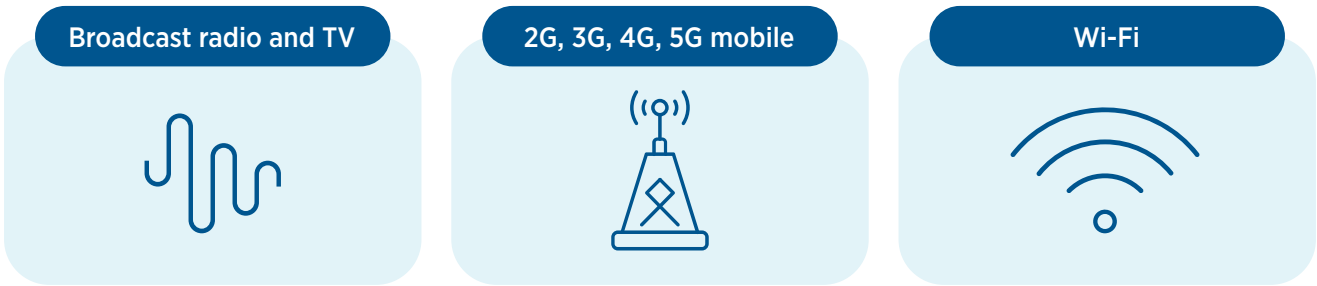
Summary

The International Commission for Non-Ionizing Radiation Protection (ICNIRP) is an independent expert scientific commission that provides scientific advice and guidance on the health and environmental effects of non-ionizing radiation (NIR) to protect people and the environment. It works with the World Health Organization (WHO) and other government agencies. ICNIRP members are not employed by industry and funding comes from national and international public institutions.

In March 2020, ICNIRP produced updated guidelines that ensure the protection of people against all established health hazards when they are exposed to radiofrequency electromagnetic fields (RF-EMF) in the range 100 kHz to 300 GHz.[1]



ICNIRP states:[2]
'The guidelines have been developed after a thorough review of all relevant scientific literature, scientific workshops and an extensive public consultation process. They provide protection against all scientifically substantiated adverse health effects due to EMF exposure in the 100 kHz to 300 GHz range.'

The updates to the limits are based on improved scientific accuracy and provide limits for exposure circumstances that were not considered in the ICNIRP (1998) guidelines. The consensus of expert reviews[3] is that there are no established health risks for mobile devices or base stations that comply with the limits in the ICNIRP guidelines.

> The main conclusion from the WHO reviews is that EMF exposures below the limits recommended in the ICNIRP international guidelines do not appear to have any known consequence on health[4].
>
> **World Health Organization**

1 https://www.icnirp.org/en/activities/news/news-article/rf-guidelines-2020-published.html
2 https://www.icnirp.org/cms/upload/presentations/ICNIRP_Media_Release_110320.pdf
3 https://www.gsma.com/publicpolicy/consumer-affairs/emf-and-health/expert-reports
4 https://www.who.int/teams/environment-climate-change-and-health/radiation-and-health/protection-norms

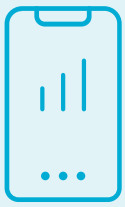
The process of producing the updated ICNIRP (2020) guidelines took seven years and included a formal public consultation phase in 2018.

ICNIRP states that there is no evidence that additional precautionary measures will result in a benefit to the health of the population. ICNIRP strongly recommends that countries update national regulations to align with the ICNIRP (2020) guidelines. Several countries are implementing the updated ICNIRP guidelines in national rules.

ICNIRP concluded that the ICNIRP (1998) guidelines, which are the basis of policy in many countries, are conservative in most cases and provide adequate protection for current technologies. Accordingly, the main ICNIRP (1998) restrictions are retained in the updated ICNIRP (2020) guidelines. ICNIRP developed more detailed exposure guidance for some cases and in particular for the frequency range above 6 GHz.

Mobile networks

There are few changes of significance for mobile networks. However, the expanded frequency range for basic restrictions and new local exposure limits may have practical implications in some exposure situations.



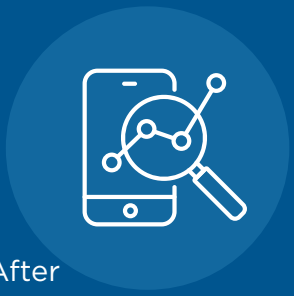
Mobile devices

The values of the mobile devices the limits are unchanged below 6 GHz. The updated power density limits have direct applications for the assessment of mobile and portable devices operating at frequencies above 6 GHz.

Stakeholders should update materials to accurately reflect the updated scientific advice.

EMF Guidelines and Safety

The International Commission on
Non-ionizing Radiation Protection finds that



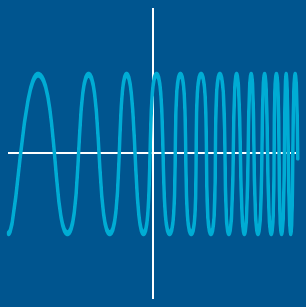
After
20+
years of more research

Input from
120
organisations
(science / industry / government)

+7
year review

2G/3G/4G/5G EMF limits similar for mobile networks and devices

Below 6GHz



Updates for
6GHz+
Improved Scientific Accuracy

Applied in
135
Countries

Limit values often
50x
below the threshold

Protecting everyone from exposure to EMF

Introduction

This document explains the key features of the updated international guidelines for exposure to radiofrequency electromagnetic fields (RF-EMFs) developed by the International Commission for Non-Ionizing Radiation Protection (ICNIRP) and published in March 2020.

Readers are advised that this document should be read in conjunction with the full ICNIRP (2020) guidelines [1] and associated publications such as the ICNIRP[5] description of the differences between the ICNIRP (2020) and previous guidelines.

This document focusses on elements of the guidelines that are most relevant for exposures from mobile communications network equipment and devices operating in the frequency range 400 MHz to 300 GHz.

Complete EMF exposure assessment of a particular situation may require consideration of sources outside this frequency range.

5 https://www.icnirp.org/en/differences.html

About ICNIRP

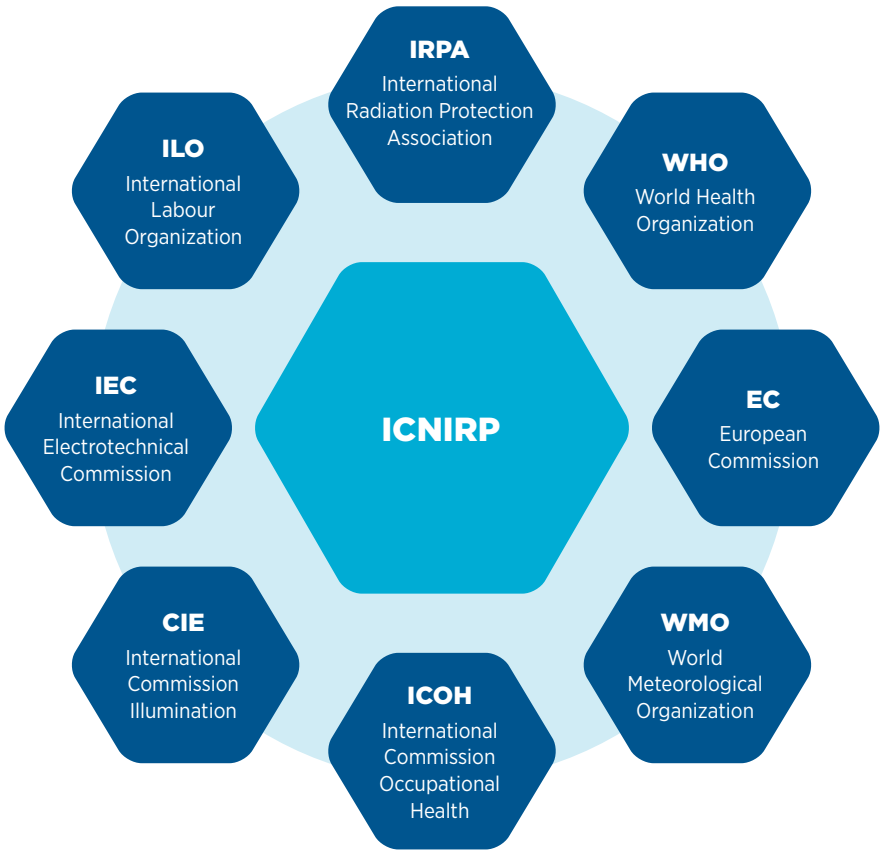
Independence of ICNIRP

ICNIRP is an independent scientific commission that works with the WHO, the International Labour Organization (ILO), the European Commission and other government agencies (see Figure 1)[6]. ICNIRP commissioners are not employed by industry and funding derives from national and international public institutions. ICNIRP members are required to declare any personal interests in relation to their activities for ICNIRP. These declarations are available from the ICNIRP website.

Commission members are experts in the scientific disciplines relevant to non-ionizing radiation protection (biology, epidemiology, physics, bio-physics, medicine). In carrying out their voluntary work for the Commission they do not represent either their countries of origin or their institutes. Members are elected to the Commission from nominations received by current members, by the Executive Council of the International Radiation Protection Association (IRPA) and the IRPA Associate Societies, and by national agencies for radiation protection following an open call for nominations published on the ICNIRP website.

Figure 1

ICNIRP works with international intergovernmental institutions and organisations



6 Adapted from https://pem.il-pib.pl/artyku%C5%82y/wytyczne-icnirp-2020/

Basis for International RF-EMF Policy

The ICNIRP (1998) guidelines are the basis for international RF-EMF policy

In 1998, ICNIRP published electromagnetic field (EMF) exposure guidelines [2] that are the basis for recommendations from World Health Organization (WHO)[7] and International Telecommunications Union (ITU)[8].

The ICNIRP (1998) guidelines have been widely adopted by national authorities and are the basis for the European Council Recommendation 1999/519/EC[9]. The vast majority of countries[10] apply public exposure limits for mobile networks based on the ICNIRP (1998) guidelines, a minority follow the US Federal Communication Commission[11] (1996) limits, and some have other limits.

The consensus of many expert reviews[12] is that there are no established health risks where RF-EMF levels comply with the limits in the ICNIRP guidelines.

ICNIRP keeps the scientific evidence under review and proposes changes where they are justified by the evidence. ICNIRP reconfirmed the 1998 guidelines in 2009[13] and 2017[14].

> The main conclusion from the WHO reviews is that EMF exposures below the limits recommended in the ICNIRP international guidelines do not appear to have any known consequence on health[15].
>
> **World Health Organization**

7 http://www.who.int/peh-emf/standards/en/
8 https://www.itu.int/en/ITU-T/emf/Pages/default.aspx
9 https://op.europa.eu/en/publication-detail/-/publication/9509b04f-1df0-4221-bfa2-c7af77975556/language-en_
10 https://www.gsma.com/publicpolicy/emf-and-health/emf-policy
11 https://www.fcc.gov/general/fcc-policy-human-exposure
12 https://www.gsma.com/publicpolicy/consumer-affairs/emf-and-health/expert-reports
13 https://www.icnirp.org/cms/upload/publications/ICNIRPStatementEMF.pdf
14 https://www.icnirp.org/en/activities/news/news-article/revision-of-hf-guidelines-2017.html
15 https://www.who.int/teams/environment-climate-change-and-health/radiation-and-health/protection-norms

ICNIRP (2020) RF-EMF guidelines

Updating the guidelines

ICNIRP completed a review of the 1998 guidelines for frequencies in the range (100 kHz - 300 GHz) and published updated RF-EMF exposure limit guidelines in March 2020.

Development of the updated ICNIRP (2020) guidelines took seven years. It included presentations at scientific conferences and a formal public consultation phase from 11 July to 9 October 2018. During the consultation[16], ICNIRP received 93 sets of comments, with over 1500 individual proposals. These were considered carefully and where appropriate the draft guidelines were amended.

The final guidelines were published both on the ICNIRP website and in the scientific journal *Health Physics.*

ICNIRP states that the guidelines will be periodically revised and updated as advances are made in the relevant scientific knowledge.

> The ICNIRP (2020) guidelines has made a number of improvements to health protection and provides more-detailed guidance for the application of its health protection system. These include the addition of whole body average restrictions for EMF frequencies above 6 GHz, restrictions for brief (< 6 minutes) exposures for EMF frequencies above 400 MHz, and the reduction of the averaging area for EMF frequencies above 6 GHz.
>
> **ICNIRP (2020)**

16 https://www.icnirp.org/en/activities/public-consultation/index.html

Main outcome of ICNIRP Health Review

ICNIRP reviewed the scientific literature to identify the health effects threshold associated with RF-EMF effects that are considered both adverse to humans and scientifically substantiated. Information was obtained from major international reviews of the literature, including an in-depth review by the WHO, and research published since the reviews.

ICNIRP considered evidence of adverse health effects from all RF-EMF exposure '*including those referred to as "low-level" and "non-thermal", and including those where mechanisms have not been elucidated.*'

All exposures were considered in terms of whether they adversely affect health.

ICNIRP concluded that the only substantiated effect of RF-EMF exposure relevant to human health is heating of exposed tissue.

ICNIRP states that '*there is no evidence that continuous (e.g., sinusoidal) and discontinuous (e.g., pulsed) EMFs result in different biological effects…*'.

Further details regarding the biological and health effects reviewed by ICNIRP are provided in Appendix B of ICNIRP (2020) [1] and summarized in Annex A of this report.

> There is no evidence of adverse health effects at exposure levels below the restriction levels in the ICNIRP (1998) guidelines and no evidence of an interaction mechanism that would predict that adverse health effects could occur due to radiofrequency emf exposure below those restriction levels.
>
> **ICNIRP (2020)**

ICNIRP (2020) scope

The updated guidelines replace the 100 kHz to 300 GHz part of the ICNIRP (1998) RF-EMF [2], as well as the 100 kHz to 10 MHz part of the ICNIRP (2010) [3] low-frequency guidelines.[17]

ICNIRP says that the updated guidelines provide a high level of protection for all people against substantiated adverse health effects from exposures to both short- and long-term, continuous and discontinuous radiofrequency EMFs.

The guidelines exclude electromagnetic compatibility (EMC) considerations, the influence of implanted metallic implants and the application of RF-EMF for medical procedures.

17 Note: ICNIRP explains that the present guidelines replace the 100 kHz to 10 MHz EMF frequency range of the ICNIRP (2010) guidelines, for adverse health effects other than direct effects on nerve stimulation from 100 kHz to 10 MHz. The restrictions relating to direct effects of nerve stimulation from the 2010 guidelines were then added to those derived in the present guidelines to form the final set of restrictions.

Principles for RF-EMF Protection

The ICNIRP guidelines specify quantitative RF-EMF levels for personal exposure. Adherence to these levels is intended to protect people from all **substantiated effects** of radiofrequency EMF exposure that are harmful to health.

ICNIRP says that the scientifically substantiated requirements may be relaxed if there is sufficient additional knowledge (such as understanding of the relevant biological interaction mechanism) to confirm that adverse health effects are reasonably expected to occur.

Scientifically substantiated

ICNIRP considers that, in general, reported adverse effects of radiofrequency EMFs on health need to be independently verified, be of sufficient scientific quality and consistent with current scientific understanding, in order to be taken as "evidence" and used for setting exposure restrictions.

ICNIRP adopts a conservative approach to developing the guidelines '*in order to ensure that its limits would remain protective even if exceeded by a substantial margin.*'

Further description of the principles for protection are provided in another ICNIRP publication [4].

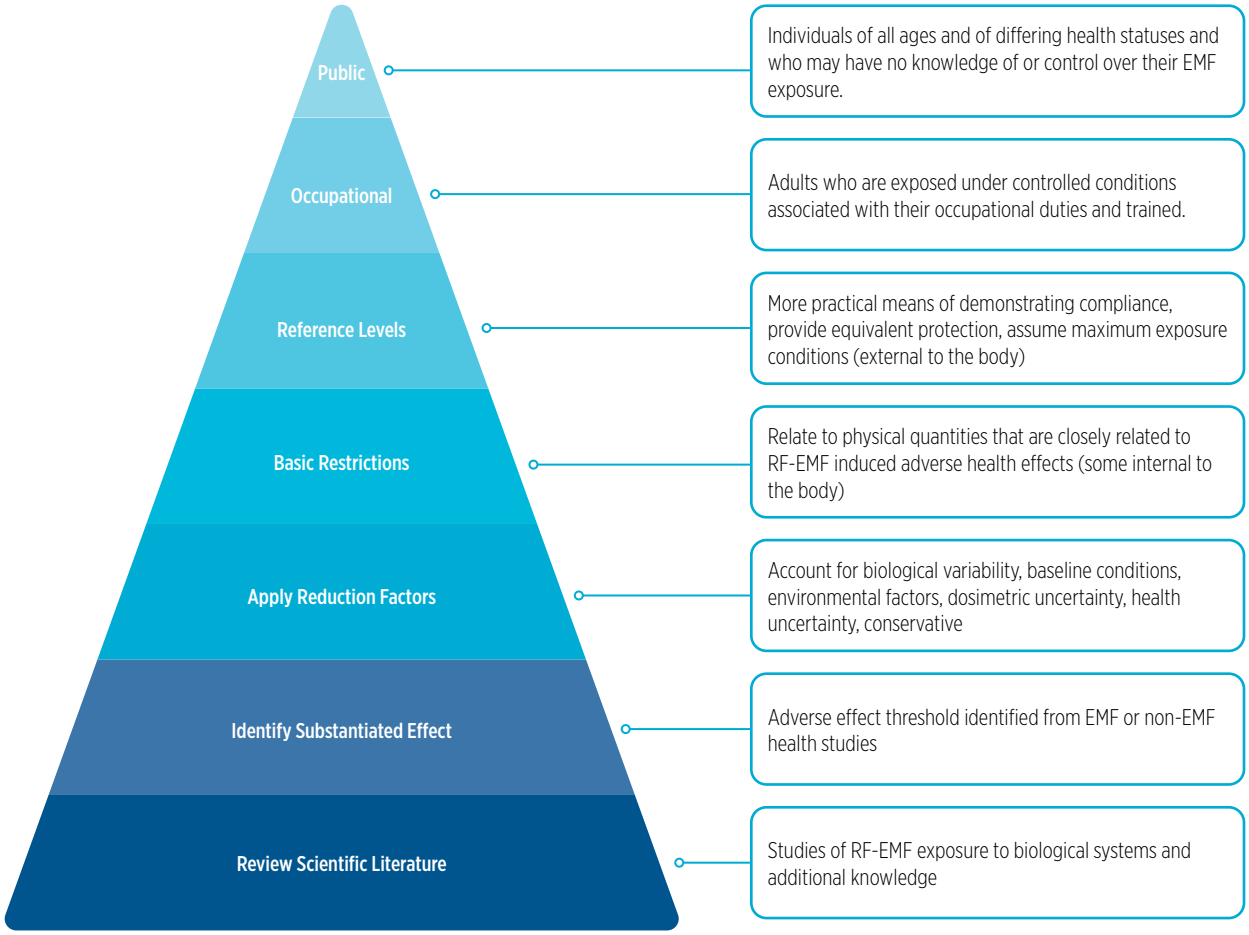
> There is no evidence that additional precautionary measures will result in a benefit to the health of the population.
>
> **ICNIRP (2020)**

The conservative approach used by ICNIRP to develop the RF-EMF limit values is illustrated in Figure 2.

The **adverse health effect threshold** for each substantiated harmful effect was derived to be '*strongly conservative for typical exposure situations and populations.*' It was determined from either RF-EMF studies (**EMF-derived threshold**) or from additional knowledge, such as heat effects studies (**operational threshold**). Note, the operational threshold approach is only used when the resulting limits would be more conservative than the EMF-derived threshold.

Figure 2

ICNIRP's conservative approach to developing RF-EMF limit values



Similar to previous guidelines, ICNIRP applied **reduction factors** to the thresholds to determine the limit values. Unlike the 1998 guidelines the reduction factors vary.

Also similar to previous guidelines, ICNIRP specifies both **basic restrictions** and **reference levels** and states that these provide '*equivalent protection.*' However, as conservative assumptions are used in deriving the reference levels in most cases ICNIRP says that '*observing the reference levels will result in substantially lower exposures than the corresponding basic restrictions allow.*'

Occupational and public exposure limits

The updated ICNIRP guidelines retain differing limits for occupationally exposed individuals and members of the general public, with more stringent restrictions for the public.

Occupationally-exposed

Adults who are exposed under controlled conditions associated with their occupational duties, trained to be aware of potential radiofrequency EMF risks and to employ appropriate harm-mitigation measures, and who have the sensory and behavioural capacity for such awareness and harm mitigation response. An occupationally-exposed worker must also be subject to an appropriate health and safety program that provides the above information and protection.

The higher limits allowed for occupationally-exposed individuals does not mean that they are at greater risk so long as appropriate screening and training is provided. ICNIRP (2020) states that an appropriate health and safety program is required.

Such a program would include consideration of the potential for RF-EMF to add to other sources of heating. ICNIRP advises that where there could be significant heat from other sources, workers should have a way to verifying core body temperature and take appropriate action if required.

General public

Individuals of all ages and of differing health statuses, which includes more vulnerable groups or individuals, and who may have no knowledge of or control over their exposure to EMFs.

ICNIRP (2020) defines the foetus as a member of the general public, regardless of exposure scenario, and subject to the general public restrictions.

Pregnant woman

A pregnant woman is treated as a member of the public. According to ICNIRP recent studies suggest that for both whole-body and local exposure scenarios, exposure of the mother at the occupational basic restrictions can lead to foetal exposures that exceed the general public basic restrictions.

ICNIRP explains that there is that there is no direct evidence that occupational whole-body exposure of the pregnant worker will harm the foetus and the decision to treat a pregnant worker as a member of the general public is conservative. They also note that there are mitigating measures that can be considered in order to allow pregnant workers to enter areas where radiofrequency EMFs are at occupational exposure levels, without exceeding the general public restrictions.

ICNIRP provides an example: within a 30-min averaging interval, a pregnant worker could be within an area at the occupational exposure restriction level for 6 min, providing that the SAR averaged over 30 min (which includes this 6-min interval) does not exceed the general public restrictions.

Health Effects Thresholds

Protection against established adverse health effects

In the updated guidelines ICNIRP concludes that the only substantiated adverse health effects caused by RF-EMF exposure above 10 MHz are due to temperature elevation.[18]

Temperature elevation

Temperature elevation is the ICNIRP identified mechanism of relevance for the frequencies used for telecommunication services and restrictions are set to avoid '*significant*' increase in temperature.

ICNIRP differentiates between steady-state temperature rises (where temperature increases slowly, allowing time for heat to dissipate and for body thermoregulatory processes to take effect), and brief temperature rises (where there may not be sufficient time for heat to dissipate). The temperature rise thresholds for steady-state exposures[19] are listed in Table 1 (page 15) and summarized below.

Whole-body core temperature

The +1°C operational-threshold derives from guidance for work environments. ICNIRP selected 4 W/kg[20] as a conservative[21] EMF-threshold and this was extended to 300 GHz (in the 1998 guidelines it stopped at 10 GHz).

The averaging time was changed to 30-min to account for the time it takes the whole-body to reach steady-state temperature.

Local temperature

The operational thresholds of +5°C for Type 1[22] tissues and +2°C for Type 2[23] tissues are based on limiting local temperatures to less than 41°C. From 100 kHz to 6 GHz, ICNIRP retains local SAR limits based on 10-g mass[24] with EMF–thresholds of 40 W/kg for Type 1 and 20 W/kg for Type 2 tissues.

As the RF-EMF energy is absorbed superficially[25] at higher frequencies, from 6 GHz[26] to 300 GHz ICNIRP specifies a new local absorbed power density (S_{ab}) EMF-threshold of 200 W/m^2 for both Type 1 and Type 2 tissues with averaging area of 4 cm^2 and an additional restriction[27] of 400 W/m^2 with averaging area of 1 cm^2 for frequencies >30 GHz.

The averaging time for both SAR and S_{ab} was kept at 6-min as it closely matches the thermal time constant for local exposure.

The whole-body and local temperature operational effects thresholds and the corresponding EMF thresholds are summarized in Figure 3 and Table 1.

18 Nerve stimulation effects can occur up to 10 MHz. A sufficiently intense and short EMF pulse may cause cell membranes to become permeable (electroporation), which in turn can lead to other cellular changes. Radiocommunication systems do not produce such exposures and so these are not discussed further here.
19 The brief temperature rise thresholds are not further discussed here.
20 For comparison, a human adult generates 1 W/kg at rest, 2 W/kg standing and 12 W/kg running. ICNIRP notes that the higher ratio of a child's surface area to body mass means that the body core temperature rise in the child is smaller than that of the adult at the same whole-body average SAR.
21 ICNIRP notes research showing that a whole-body SAR of 6 W/kg (100 kHz to 6 GHz) for at least 1-hr is needed to raise adult core temperature by +1°C. A higher SAR is needed for children as they dissipate heat more efficiently.
22 Type 1 tissues: all tissues in the upper arm, forearm, hand, thigh, leg, foot, pinna and the cornea, anterior chamber and iris of the eye, epidermal, dermal, fat, muscle, and bone tissue.
23 Type 2 tissues: all tissues in the head, eye, abdomen, back, thorax, and pelvis, excluding those defined as Type-1 tissue.
24 A 10-g volume is approximately a 2.15 cm x 2.15 cm x 2.15 cm cube, based on the assumption that the tissue has the same mass density as water, 1,000 kg/m^3.
25 For example, the penetration depths are approximately 8.1 mm and 0.23 mm at 6 GHz and 300 GHz, respectively.
26 The choice of 6 GHz is a practical compromise relevant to the spatial and temporal averaging conditions.
27 As the frequency increases it becomes possible to focus exposure to a smaller area.

Figure 3

ICNIRP (2020) whole-body and local exposure thresholds

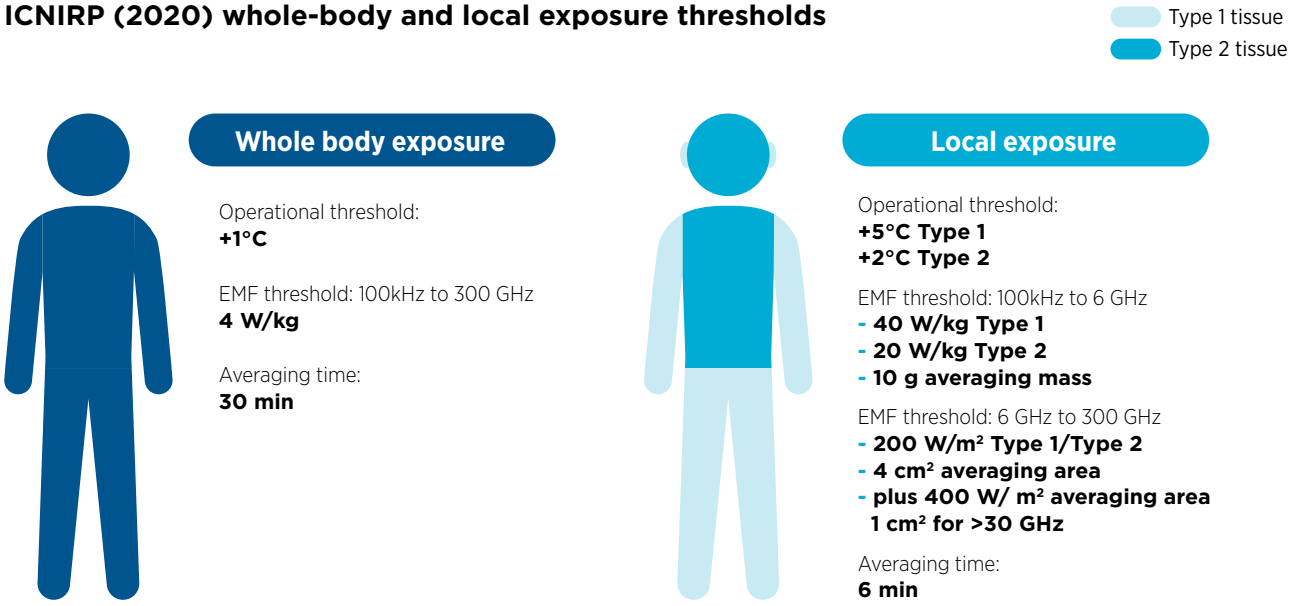


Table 1

ICNIRP steady-state operational-thresholds, EMF-thresholds and basic restrictions for occupational and public exposures

	Core body temperature	Local temperature (Head, Torso)	Local temperature (Limbs)	Local temperature (Head, Torso, Limbs)	
Frequency range	100 kHz – 300 GHz	100 kHz – 6 GHz	100 kHz – 6 GHz	>6 – 300 GHz	30 – 300 GHz
Operational threshold	+1°	+2°	+5°	+5°	+5°
Spatial averaging	WBA	10 g	10 g	4 cm^2	1 cm^2
Temporal averaging	30 min	6 min	6 min	6 min	6 min
EMF threshold	4 W/kg	20 W/kg	40 W/kg	200 W/m^2	400 W/m^2
Reduction factor	10	2	2	2	2
Occupational	0.4 W/kg	10 W/kg	20 W/kg	100 W/m^2	200 W/m^2
Reduction factor	50	10	10	10	10
Public	0.08 W/kg	2 W/kg	4 W/kg	20 W/m^2	40 W/m^2

Note: WBA = Whole-body average.

ICNIRP Basic Restrictions

RF-EMF limits based on thresholds for established health effects

ICNIRP derived the basic restrictions from the thresholds for RF-EMF induced health effects as discussed on page 14. The values of the basic restrictions[28] for workers and the public are shown in Table 1 along with the reduction factors.

ICNIRP states that to comply with the revised guidelines for each exposure quantity, and temporal and spatial averaging condition, either the basic restriction or corresponding reference level must be adhered to; compliance with both is not required.

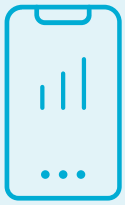
Also, to be compliant RF-EMF exposure must not exceed any of the basic restrictions that apply for the specified frequency.

Whole-body SAR

The values for the whole body SAR limits for workers and the public are unchanged between the ICNIRP (1998) and the ICNIRP (2020) guidelines. The whole body SAR limit is extended to 300 GHz whereas in the ICNIRP (1998) guidelines it stopped at 10 GHz. The averaging time is changed to 30-min whereas it was 6-min in the ICNIRP (1998) guidelines.

ICNIRP comments that this would justify less conservative reduction factors (implying higher basic restrictions) but the whole body SAR limits are unchanged to maintain stability in the guidelines.

> It is noteworthy that the scientific uncertainty pertaining to both dosimetry and potential health consequences of whole-body radiofrequency exposure have reduced substantially since the ICNIRP (1998) guidelines.
>
> **ICNIRP (2020)**



Mobile devices

The values of the mobile devices the limits are unchanged below 6 GHz. The updated power density limits have direct applications for the assessment of mobile and portable devices operating at frequencies above 6 GHz.

28 ICNIRP also provides basic restrictions for brief exposures and peak spatial values.

Local SAR

The values for the local SAR limits for workers and the public are unchanged between the ICNIRP (1998) and the ICNIRP (2020) guidelines. The local SAR limits stop at 6 GHz whereas in the 1998 guidelines they stopped at 10 GHz. The averaging mass remains the same, 10 g. The averaging time is unchanged at 6-min. ICNIRP says that the smaller reduction factors for local exposure, relative to those for whole-body exposure, are justified because the associated health effect threshold is less dependent on environmental conditions and because the associated health effect is less serious medically.

Local absorbed power density

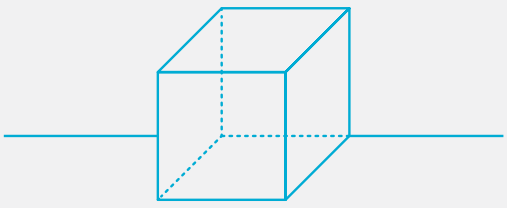
Local absorbed power density (S_{ab}) is a new basic restriction that takes account of the more superficial absorption of RF-EMF as the frequency increases and applies above 6 GHz. SAR and S_{ab} are compared in Figure 4.

Figure 4

Comparison of SAR and local absorbed power density.

Local SAR (Specific Absorption Rate)

- Absorption in tissue volume
- 100 kHz to 6 GHz
- Cube of 10 g



10 g cube

Local S_{ab} (absorbed power density)

- Absorption at the surface
- 6 to 300 GHz
- Average over 4 cm^2. Above 30 GHz additional restriction on average over 1 cm^2

4 cm^2 area
(with 1 cm^2 area >30 GHz)

ICNIRP Reference Levels

Practical means of demonstrating compliance

The reference levels have been derived by ICNIRP from computational and measurement studies. They represent a practical means of demonstrating compliance using quantities that are more-easily assessed than basic restrictions and provide an equivalent level of protection for conditions of maximum exposure scenarios.

ICNIRP notes that the reference levels rely on conservative assumptions and in most exposure scenarios the reference levels will be more conservative than the corresponding basic restrictions.

As will be seen in the following sections, reference levels are specified with averaging and integration times for the relevant exposure quantities to determine whether an exposure complies with the guidelines.

In order to ensure that the reference levels adequately predict the basic restrictions, different reference level assessment rules have been set depending on whether they are within the far-field, radiative or reactive near-field zone, see page 22.

As a guide, ICNIRP provides definitions for these zones and notes that information from technical standards bodies should be used to improve assessment procedures for reference levels.

Another change in the ICNIRP (2020) guidelines is that for every basic restriction there is a corresponding reference level. In practical terms it means that ICNIRP (2020) includes both whole-body and local reference levels whereas ICNIRP (1998) included only whole-body reference levels.

Whole body reference levels

The whole body exposure reference levels for frequencies above 400 MHz (with the ICNIRP (1998) equivalents) are shown in Table 2 and in graphical form in Figure 5.

Mobile networks

There are few changes of significance for mobile networks. However, the expanded frequency range for basic restrictions and new local exposure limits may have practical implications in some exposure situations, for example, compliance of small cells.

Note that the averaging time is 30 min.

While there are no changes to the values for the reference levels above 400 MHz, there is a change to the field quantities that are specified. Above 2 GHz, ICNIRP (2020)[29] provides only incident power density limits and no equivalent electric or magnetic field limits.

ICNIRP also says that the plane wave equivalent power density (S_{eq}) can be used in place of S_{inc} in the far-field (30 MHz to 300 GHz).

29 According to ICNIRP, E-field and H-field values do not always provide a good estimate of the basic restriction values above approximately 2 GHz.

Table 2

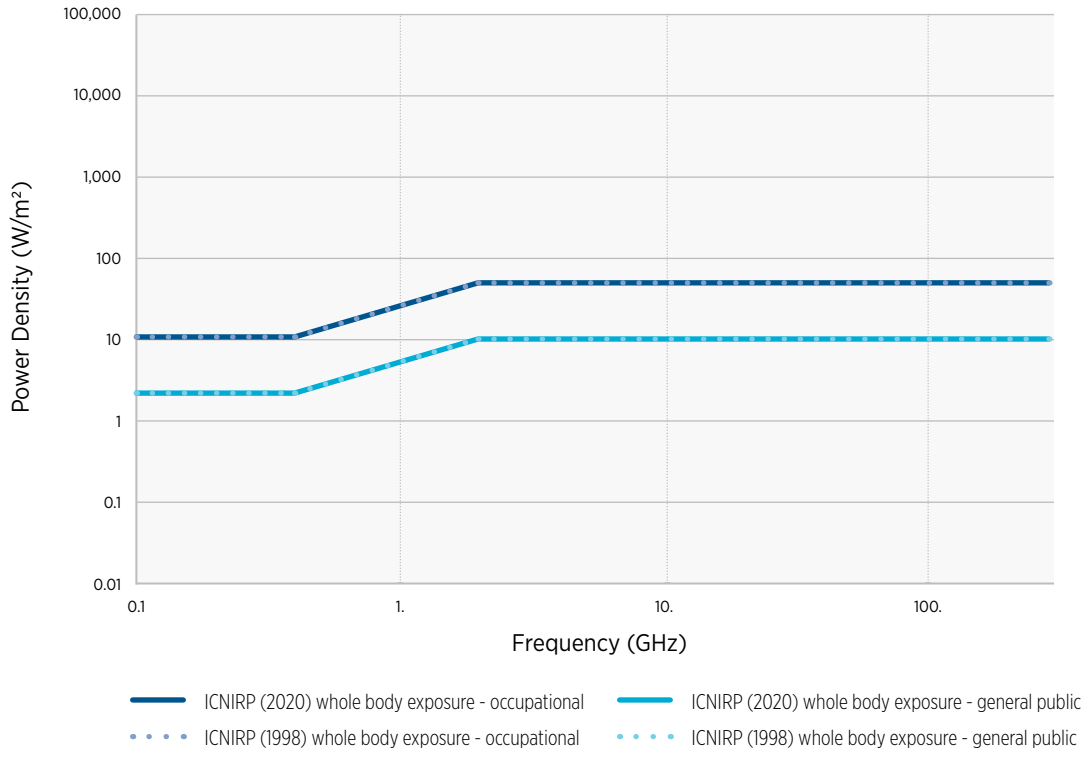
ICNIRP (2020) reference levels averaged over the whole body and 30 min

Exposure scenario	Frequency range	Incident E-field strength; E_{inc} (V/m)	Incident H-field strength; H_{inc} (A/m)	Incident power density; S_{inc} (W/m^2)
Occupational	>400 – 2000 MHz	$3f_M^{0.5}$	$0.008f_M^{0.5}$	$f_M/40$
	>2 – 300 GHz	NA	NA	50
General public	>400 – 2000 MHz	$1.375f_M^{0.5}$	$0.0037f_M^{0.5}$	$f_M/200$
	>2 – 300 GHz	NA	NA	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}, E_{inc}, and H_{inc} are to be averaged over 30 min, 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 of ICNIRP (2020) for details).
4. For frequencies of >30MHz 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.
5. 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

Figure 5

ICNIRP (2020) whole-body reference levels for workers and the public with ICNIRP (1998) equivalents



Local exposure reference levels

In a new development, the ICNIRP (2020) guidelines include local exposure reference levels. These are shown for frequencies above 400 MHz in Table 3 and in graphical form in Figure 6.

For frequencies <6 GHz the averaging time is 6-min, the same as the local exposure basic restrictions (page 17). For frequencies >6 GHz the averaging area is 4 cm^2 with the additional restriction that above 30 GHz, exposure over 1cm^2 must not exceed twice the 4 cm^2 restriction.

Table 3

ICNIRP (2020) reference levels for local exposure and averaged over 6 min

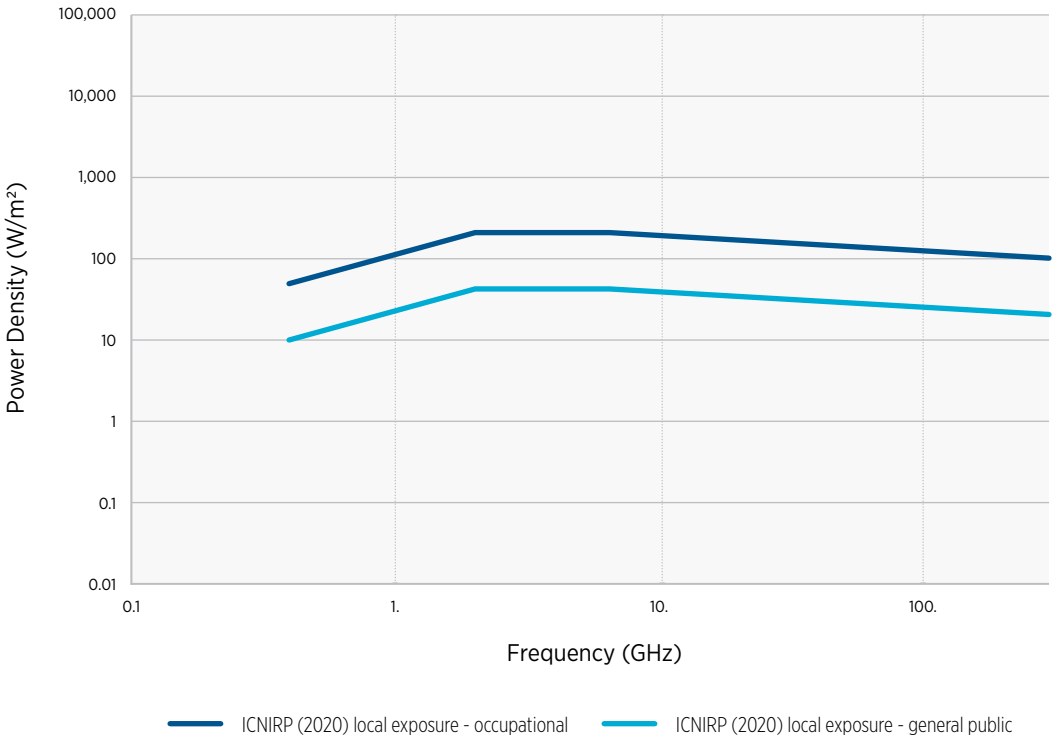
Exposure scenario	Frequency range	Incident E-field strength; E_{inc} (V/m)	Incident H-field strength; H_{inc} (A/m)	Incident power density; S_{inc} (W/m^2)
Occupational	>400 – 2000 MHz	$3f_M^{0.5}$	$0.008f_M^{0.5}$	$0.29f_M^{0.86}$
	>2 – 6 GHz	NA	NA	200
	>6 GHz - <300 GHz	NA	NA	$275/f_G^{0.177}$
	300 GHz	NA	NA	100
General public	>400 – 2000 MHz	$1.375f_M^{0.5}$	$0.0037f_M^{0.5}$	$0.058f_M^{0.86}$
	>2 – 6 GHz	NA	NA	40
	>6 GHz - <300 GHz	NA	NA	$55/f_G^{0.177}$
	300 GHz	NA	NA	20

Note:

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}, E_{inc}, and H_{inc} are to be averaged over 6 min, 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 of ICNIRP (2020) for details).
5. For frequencies of >30MHz 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.

Figure 6

ICNIRP (2020) reference levels for local exposure, averaged over 6 min



It is expected that the local exposure reference levels could be used for compliance of RF-EMF products that locally expose the body where this is consistent with ICNIRP (2020) provisions for near-field/far-field zones (see page 22).

ICNIRP Guidance on Compliance

In this section we summarize some of the guidance provided in the ICNIRP (2020) guidelines regarding demonstrating compliance.

Governments are responsible for determining the rules for demonstrating compliance to RF-EMF limits. GSMA recommends that compliance methods are based on international technical standards.

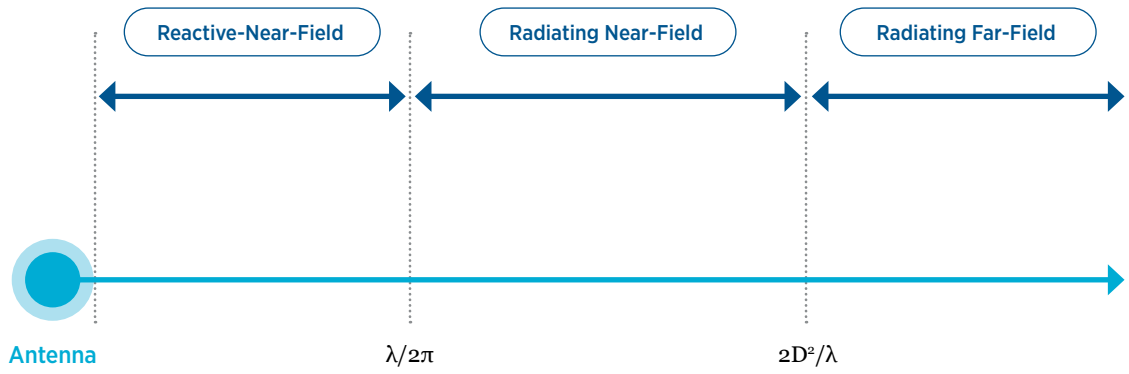
Antenna field zones

The ICNIRP (2020) definitions of the near-field/far-field zones are presented in Figure 7 and the rules for antenna field zone compliance are summarised in Table 4.

Figure 7

ICNIRP (2020) definitions of antenna field zones

Where D and λ respectively refer to the longest dimension of the antenna and wavelength.



It should be noted that ICNIRP states that in the reactive near-field basic restrictions must be assessed.

Table 4

Summary of ICNIRP (2020) field zone compliance rules for frequencies from 400 MHz to 300 GHz

	Averaging time	Frequency range	Field zone	Compliance demonstrated if
Whole-body	30 min	>400 – 2000 MHz	Far-field	either S_{inc}, E_{inc} or H_{inc}, does not exceed the reference level values (only one is required)
			Radiative near-field	either S_{inc}, or both E_{inc} and H_{inc}, does not exceed the reference level values
			Reactive near-field	both E_{inc} and H_{inc}, do not exceed the reference level values; S_{inc} cannot be used to demonstrate compliance, **basic restrictions** must be assessed
		>2 – 300 GHz	Far-field	S_{inc} does not exceed the reference level values
			Radiative near-field	S_{inc} does not exceed the reference level values
			Reactive near-field	reference level values cannot be used to demonstrate compliance, **basic restrictions** must be assessed
Local	6 min	>400 – 6000 MHz	Far-field	one of peak spatial S_{inc}, E_{inc} or H_{inc}, over the projected whole-body space, does not exceed the reference level values (only one is required) S_{eq} may be substituted for S_{inc}.
			Radiative near-field	either peak spatial S_{inc}, or both peak spatial E_{inc} and H_{inc}, over the projected whole-body space, does not exceed the reference level values
			Reactive near-field	both E_{inc} and H_{inc}, do not exceed the 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 – 300 GHz	Far-field	S_{inc}, averaged over a square 4-cm^2 projected body surface space, does not exceed the reference level values
			Radiative near-field	S_{inc}, averaged over a square 4-cm^2 projected body surface space, does not exceed the reference level values
			Reactive near-field	reference levels cannot be used to determine compliance, and so **basic restrictions** must be assessed

Note: In the far-field S_{eq} may be substituted for S_{inc}. For local exposure at 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. S_{eq} may be substituted for S_{inc}.

Multiple frequency exposures

In the case of multiple frequency exposures, ICNIRP (2020) requires evaluation of the fraction of the applicable limit(s)[30] for each frequency and that the sum of all the fractions should be ≤1. Where applicable the evaluation can be made based on a mixture of basic restrictions and reference levels. Detailed formulas are provided in ICNIRP (2020) that are not duplicated here.

Measurement averaging time

One of the changes in ICNIRP (2020) is that the whole-body averaging time is now 30-min (see page 14).

The averaging times are not necessarily the same as the measurement times needed to estimate field strengths or other exposure quantities. ICNIRP states that depending on input from technical standards bodies, actual measurement times may be shorter than the specified intervals.

For example, Appendix V of ITU-T K.100 [5] shows that for measurements of some base stations a 60-sec averaging period was sufficient. Alternatively, reference signals or channels can be measured and extrapolated to assess exposure [6].

30 ICNIRP (2020) states that it is important to determine whether, in multiple frequency exposure situations, the exposures are additive in their effects. ICNIRP (2020) points out that additivity should be examined separately for the effects of thermal and electrical stimulation, and restrictions met after accounting for such additivity. Electrical stimulation limits apply up to 10 MHz and so are not relevant for mobile communication sources.

Implications and Conclusions

The ICNIRP (2020) guidelines are up-to-date recommendations for human exposure limits to provide protection for all persons against established adverse health effects of exposure to RF-EMF. The updates to the limits are based on improved scientific accuracy and provide limits for exposure circumstances that were not considered in the ICNIRP (1998) guidelines.

ICNIRP concludes that no adverse health effects were identified below the ICNIRP (1998) limits and there is no mechanism that would predict adverse health effects at exposures below the limit values.

In ICNIRP (2020) there are few changes of significance for mobile networks. However, the expanded frequency range for basic restrictions and new local exposure limits may have practical implications in some exposure situations, for example, compliance assessment of small cell equipment.

For mobile devices the ICNIRP (2020) changes to the frequency range for local SAR limits and the updated/new local and incident power density limits have direct applications for the assessment of mobile and portable devices operating at frequencies above 6 GHz.

ICNIRP says that additional precautionary measures provide no additional health benefits. Where policymakers have adopted restrictive RF-EMF limits these should be updated to the ICNIRP (2020) guidelines. Also, it should be noted that providing recommendations to further reduce exposure causes anxiety [7] and is inconsistent with the ICNIRP (2020) guidelines.

For all stakeholders there is a need to update communication materials to accurately reflect the latest advice on exposure limits and evaluation of the scientific literature.

ICNIRP strongly recommends that countries update national regulations to align with the ICNIRP (2020) guidelines.

Several countries are implementing the updated ICNIRP guidelines in national rules[31].

31 https://www.gsma.com/publicpolicy/emf-and-health/emf-policy

Annex A: ICNIRP health risk assessment summary

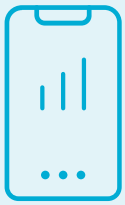
Appendix B of ICNIRP (2020) sets out the scientific reviews relied upon by ICNIRP. Key documents include:

- **2014:** WHO Public Consultation Environmental Health Criteria Document (EHC)
- **2015:** European Commission Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR)
- **2015-2018:** Swedish Radiation Safety Authority (SSM) reports
- **Other more recent research** - cut-off 1 September 2019

The overall conclusion of the ICNIRP (2020) review is that the only substantiated adverse health effects of RF-EMF exposure are nerve stimulation, changes in the permeability of cell membranes, and effects due to temperature elevation.

The ICNIRP (2020) conclusions on a range of health endpoints are summarized in Table 5.

In regard to cancer risk ICNIRP notes that suggestions of increased risks in some epidemiological studies are '*not consistent with trends in brain cancer incidence rates from a large number of countries or regions, which have not found any increase in the incidence since mobile phones were introduced.*' ICNIRP also says that two recent animal studies of cancer have important limitations[32] and their '*their findings do not provide evidence that radiofrequency EMFs are carcinogenic.*' See also [8].



Mobile devices

'...trends in brain cancer incidence rates from a large number of countries or regions, which have not found any increase in the incidence since mobile phones were introduced.'

Base stations

'Taken together, the epidemiological studies do not provide evidence of a carcinogenic effect of radiofrequency EMF exposure at levels encountered in the general population.'

32 The two studies are by the U.S. National Toxicology Program and the Italian Ramazzini Institute. See [8].

Table 5

Summary of ICNIRP (2020) conclusions on adverse health effects

Health effect	ICNIRP summary
Brain electrical activity and cognitive performance	There is no substantiated experimental or epidemiological evidence that exposure to radiofrequency EMFs affects higher cognitive functions relevant to health.
Symptoms and wellbeing	No reports of adverse effects of radiofrequency EMF exposures on symptoms and wellbeing have been substantiated, except for pain, which is related to elevated temperature at high exposure levels.
Other brain physiology and related functions	There is no evidence of effects of radiofrequency EMFs on physiological processes that impair human health.
Auditory, vestibular, and ocular function	No reported effects on auditory, vestibular, or ocular function or pathology relevant to human health have been substantiated.
Neuroendocrine system	The lowest level at which an effect of radiofrequency EMFs on the neuroendocrine system has been observed is 4 W/kg (in rodents and primates), but there is no evidence that this translates to humans or is relevant to human health. No other reported effects have been substantiated.
Neurodegenerative diseases	In summary, no adverse effects on neurodegenerative diseases have been substantiated.
Cardiovascular system, autonomic nervous system, and thermoregulation	No effects on the cardiovascular system, autonomic nervous system, or thermoregulation that compromise human health have been substantiated for exposures with whole-body average SARs below approximately 4 W/kg, with harm only found in animals exposed to whole-body average SARs substantially higher than 4 W/kg.
Immune system and haematology	The few human studies that have been conducted have not provided any evidence that radiofrequency EMFs affect health in humans via the immune system or haematology.
Fertility, reproduction, and childhood development	No adverse effects of radiofrequency EMF exposure on fertility, reproduction, or development relevant to human health have been substantiated.
Cancer	No effects of radiofrequency EMFs on the induction or development of cancer have been substantiated.

Annex B: Questions and answers

The text in this section is based on answers provided on the ICNIRP[33] website.

What are the main differences between the (2020) ICNIRP RF Guidelines and previous (1998) ICNIRP RF EMF guidelines?

There is a range of differences between the new and old guidelines. The main changes relate to EMF exposures above 6 GHz, and account for technological developments of RF EMF, such as 5G. These include additional restrictions to ensure that whole body and brief (< 6 minutes) local RF EMF exposures will not result in excessive exposures. Within this >6 GHz EMF frequency range, the averaging area for local exposure has also been reduced, by a factor of 5. This reduces the maximum exposure of a person relative to the ICNIRP (1998) restrictions. Other minor changes to the guidelines include additional means of assessing compliance with the guidelines; and greater specification of how to assess complicated exposure scenarios.

What does ICNIRP recommend for countries with the ICNIRP (1998) RF-EMF guidelines?

The ICNIRP (1998) guidelines are protective for current commercial applications of RF EMFs. However, the new guidelines have incorporated a number of important additions and changes, particularly for EMF frequencies above 6 GHz. Accordingly, and particularly in relation to current and future technological development such as 5G, it is strongly recommended that countries update to the new ICNIRP (2020) guidelines.

33 https://www.icnirp.org/en/rf-faq/index.html

How are specific populations, such as children, pregnant women, sick and elderly people, protected in the RF EMF guidelines?

The guidelines use a range of mechanisms to ensure that all people are protected from RF EMF exposure. One of these is the use of reduction factors, that ensure that the restrictions are far lower than are required to cause adverse health effects for all people.

Does ICNIRP consider non-thermal effects of RF EMF on health?

Yes, ICNIRP considers all potential adverse health effects, and sets restrictions to ensure that none occur, regardless of the mechanism of interaction between the exposure and the body. The lowest exposure levels that can cause adverse health effects are due to thermal mechanisms, and so restrictions have been set based on the thermal effects, as these will protect against any other effects that could occur at higher exposure levels.

Do the new guidelines cover exposures from 5G?

Yes, the new guidelines protect against all potential adverse health effects relating to exposure to RF EMF from 5G technologies. It is important to note that the ICNIRP (1998) guidelines will also provide protection for 5G technologies if they produce the exposure levels that are so far predicted; these are predicted to be approximately similar to the exposures from previous mobile telecommunications technologies (e.g. 4G). However, ICNIRP (2020) has made a number of changes that do not rely on such predictions, and that will ensure that 5G is not able to cause harm.

Annex C: Key technical changes

The table below summarizes the main technical changes in ICNIRP (2020) relative to ICNIRP (1998) for frequencies 400 MHz to 300 GHz. In general changes have been made for improved accuracy of exposure based on newer studies.

Change	ICNIRP (1998)	ICNIRP (2020)	Explanation
Frequency range	0 to 300 GHz	100 kHz to 300 GHz	Lower frequencies are covered by ICNIRP (2010) guidelines [3].
Whole body SAR basic restriction	100 kHz to 10 GHz	100 kHz to 300 GHz	New research shows potential for whole-body heating at higher frequencies as blood flow can carry heat throughout the body.
Averaging time for whole-body exposures	6 min	30 min	Better relationship to the time taken for whole-body temperature rise.
Averaging mass for local SAR	10 g of contiguous tissue, 100 kHz to 10 GHz	10 g of tissue in the shape of a cube, 100 kHz to 6 GHz	Better relationship with local temperature increase. Frequency change is practical compromise in the transition from SAR to absorbed power density.
Local exposure basic restriction	Incident power density, 10 – 300 GHz	Absorbed power density, 6 to 300 GHz	Better measure of the exposure internal to the body given that up to 50% of incident power density is reflected at the surface of the body. Frequency change is practical compromise in the transition from SAR to absorbed power density.
Averaging area for local power density	20 cm^2 (>10 GHz)	4 cm^2 (>6 GHz) plus 1 cm^2 (>30 GHz)	Area change gives a better transition from SAR to power density (10 g cube has edge length of 2.2 cm). The additional restriction above 30 GHz limits potential for localized heating by focused beams.

Change	ICNIRP (1998)	ICNIRP (2020)	Explanation
Averaging time for local power density	6 min (<10 GHz) $68/f^{1.05}$ min (>10 GHz)	6 min (>6 GHz)	Better relationship with local temperature increase. Frequency change is practical compromise in the transition from SAR to absorbed power density.
Basic restrictions for brief (<6-min) and intense local exposure	Specific absorption 0.3 to 10 GHz and power density (>10 GHz)	Specific absorption (>400 MHz to 6 GHz) and absorbed energy density (>6 GHz) Limits set as function of exposure duration (>0 to <6 min)	Better relationship with local temperature increase and ensure that local heating from pulses can't cause pain or tissue damage. Microwave hearing effect no longer explicitly addressed but protected by updated limits.
Whole body reference levels	Equivalent plane wave E-field, H-field and power density (400 MHz to 300 GHz)	Incident E-field, H-field (400 MHz to 2 GHz) Incident power density (400 MHz to 300 GHz) Equivalent plane wave power density (only in the far-field)	E-field and H-field levels are not always a good estimate of the basic restrictions above 2 GHz. Equivalent plane wave parameters are only permitted in the far-field zone to better match basic restrictions.
Local exposure reference levels	Not defined	New local exposure reference levels and rules on application in near-/far-field zones.	Each basic restriction has a corresponding reference level. Application rules to ensure better match to corresponding basic restriction.
Reference levels for brief (<6-min) and intense local exposure	Peak field E- and H-field strengths and equivalent plane wave power density	Incident energy density Limits set as function of exposure duration (>0 to <6 min)	Ensure compliance with basic restrictions for brief and intense local exposures.

Abbreviations

2G/3G/ 4G/5G	1st to 5th generation mobile communication technologies
3GPP	Third generation partnership project
E_{inc}	Incident E-field strength (V/m)
EMC	Electromagnetic compatibility
EMF	Electromagnetic Field
H_{inc}	Incident H-field strength (A/m)
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ILO	International Labour Organization
IRPA	International Radiation Protection Association
ITU	International Telecommunications Union
NIR	Non-ionizing radiation
RF	Radiofrequency
S_{ab}	Local absorbed power density (W/m^2)
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks
S_{eq}	Plane wave equivalent power density (W/m^2)
S_{inc}	Incident power density (W/m^2)
SAR	Specific Absorption Rate (W/kg)
SSM	Strålsäkerhetsmyndigheten (Swedish Radiation Safety Authority)
WHO	World Health Organization
Wi-Fi	Wireless network technology

References

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