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Differences between the ICNIRP (2020) and previous guidelines

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1. Preface

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has published its 2020 Guidelines for Limiting Exposure to Electromagnetic Fields (100 kHz to 300 GHz). This updates the radiofrequency electromagnetic field (RF EMF) part of the ICNIRP 1998 guidelines, and the 100 kHz to 10 MHz part of the ICNIRP (2010) low frequency guidelines. There have been a number of requests for ICNIRP to explain the differences between ICNIRP (2020) and those previous guidelines; this is the purpose of the present document. However, as the aim is to help people understand the main differences, rather than to provide a precise explication of the various guidelines, this document should not be read as an alternate to the ICNIRP (2020) guidelines. Accordingly, should there be real or apparent inconsistencies between ICNIRP (2020) and the present document, ICNIRP (2020) must be taken as the *only* document relevant to the RF guidelines.

The ICNIRP (2020) and previous guidelines can be compared in terms of the overall approach of the protection systems, as well as in terms of the restrictions themselves. The overall approach includes such issues as the scope, types of adverse health effects considered, degree of transparency built into the protection system, quantities used to set the restrictions, and the way that restrictions are determined in order to provide protection. Conversely, the restrictions are the result of this overall approach – they are a set of RF EMF values that should not be exceeded in order to ensure protection from adverse health effects. The overall approach and the restrictions themselves are considered separately.

2. Comparing the overall approach of the protection systems

2.1. Transparency

An important feature of the ICNIRP (2020) guidelines is that it has increased the level of transparency of the overall approach and resultant restrictions. This has been made possible by the great wealth of scientific research that has been conducted since the previous guidelines, with the result being that it is now possible to see the decisions made at each step of the restriction derivations. This in turn enabled ICNIRP to engage meaningfully with the scientific and lay communities to improve both minor and substantive issues in earlier drafts via its public consultation process, and provided the detail needed to enable the guidelines to be evaluated against future scientific developments. This cannot completely remove the role of expert judgement in some stages of the restriction derivation process (such as whether to conclude that an adverse health effect has been demonstrated), but the determination itself is specified, and if subsequent research shows that the decision is incorrect, then the ramifications for the exposure restrictions can be easily identified and dealt with.

2.2. Scope

The scope of both guidelines is very similar, providing protection against all adverse health effects, regardless of whether they are due to acute or chronic exposures, regardless of age or health status, and regardless of the biophysical mechanism responsible for the effect. Exposure scenarios are also very similar in the two guidelines. Further clarification of the scope has been provided in ICNIRP (2020) to remove potential ambiguities. For example, it now specifically states that cosmetic procedures are within the scope (unless being conducted under appropriate medical supervision), and that ‘carers and comforters’ of those receiving medical treatment are outside the scope (with the cost-benefit assessment for them to be conducted similar to that of the person receiving treatment, by the appropriately trained medical practitioner).

2.3. Operational adverse health effect thresholds

The previous guidelines were based on adverse health effects that had been shown to be caused by RF EMF exposure. ICNIRP (2020) used the same approach, and indeed there is now a substantial body of literature that has confirmed that RF EMF exposure within the ICNIRP (1998) restrictions does not cause adverse health effects. However, the body of scientific information has not increased greatly in terms of exposures much higher than the ICNIRP (1998) restrictions, particularly in terms of thermal effects, making it difficult to determine *thresholds* for adverse health effects (i.e. the lowest RF EMF level that will cause an adverse health effect). Given this situation, and given that there is a strong body of literature concerning the effect of heating on health from other sources, ICNIRP (2020) has used this thermal physiology knowledge to supplement that of the RF EMF literature.

2.4. Classification of the fetus

ICNIRP (1998) and ICNIRP (2010) did not differentiate between pregnant and non-pregnant workers in terms of its occupational exposure restrictions, which may result in the fetus being exposed above the more conservative general public restrictions. Although there is no evidence showing that occupational exposure of the fetus would result in adverse health effects, as a conservative measure, ICNIRP (2020) treats the fetus as a member of the general public and therefore subject to the general public restrictions. Accordingly, to ensure that fetal exposure does not exceed the exposure restrictions for the general public, ICNIRP (2020) specifies that a pregnant worker is subject to the general public restrictions.

2.5. Types of changes to the restrictions

There are a range of improvements to the ICNIRP (2020) restrictions, including the addition of new restrictions, amendments to old restrictions, and the removal of some restrictions. These changes are described separately in Section 3 below. However, as a general explanation: additional restrictions were introduced to account for situations whereby the ICNIRP (1998) restrictions would not adequately account for new technological developments, such as aspects of 5G technologies; amendments to existing restrictions were made to improve precision based on scientific advances since 1998, such as more accurate knowledge concerning the relation between spatial averaging of exposure and temperature rise; and restrictions were removed in situations where it has become clear that a particular restriction was not needed to provide protection against adverse health effects.

2.6. What the changes to the restrictions mean for health protection

It is important to note that the main restrictions specified in the previous ICNIRP guidelines provide protection against adverse health effects from exposure arising from RF EMF-emitting technologies as currently used. Accordingly, the main ICNIRP (1998) restrictions currently remain protective, and have been mostly retained in the new guidelines.

Minor changes that have been made to improve the precision of the restrictions have resulted in more-conservative restrictions, but as the differences are small relative to the strongly conservative restrictions themselves, these changes will not make an appreciable difference to health protection against exposure from current RF EMF-emitting devices.

However, there are two new restrictions in ICNIRP (2020) that have the potential to further strengthen health protection. The first relates to the development of technologies that utilise EMF frequencies >6 GHz, such as 5G, with new restrictions to better protect against excessive temperature rise in the body. The second relates to brief RF EMF exposures (<6 minutes), to ensure that transient temperature rise is not sufficient to cause pain or adversely affect tissue – although ICNIRP (1998) had a restriction for brief (circa 50 ms) pulsed RF EMF to the head, the present guidelines provide protection for exposure durations up to 6 minutes and over the whole body. ICNIRP is not aware of any situations where exposure compliant with the 1998 guidelines has resulted in transient temperature rises that has adversely affected health, but this new restriction will ensure that new or future technological uses will also not adversely affect health.

3. Technical changes to the basic restrictions

3.1. Whole body average exposure restrictions

The whole-body exposure restriction in ICNIRP (1998) was set in terms of the quantity 'SAR' (Specific energy Absorption Rate). This is also the case for ICNIRP (2020). However, whereas this restriction only applied up to 10 GHz in ICNIRP (1998), it is applicable across the entire 100 kHz to 300 GHz range in ICNIRP (2020). This will ensure that exposures from new technologies do not lead to excessive temperature rise deep in the body. The averaging time for this restriction has also been changed from 6 minutes in ICNIRP (1998) to 30 minutes in ICNIRP (2020), to better match the time taken for body core

temperature to rise. The basic restriction values themselves have not changed, as research has now shown that they were even more conservative than was originally thought.

3.2. Changes to the 'transition frequency' for local exposure

Local RF EMF restrictions use different exposure quantities for different RF EMF frequencies. In ICNIRP (1998) SAR was used up to 10 GHz, and 'power density' was used above 10 GHz; the frequency at which the quantity changes, is referred to as the 'transition frequency'. Different quantities are used because SAR may underestimate superficial exposure at higher frequencies, whereas power density may underestimate deeper exposures at lower frequencies. Although there is no ideal transition frequency, ICNIRP (2020) has taken a pragmatic approach and reduced the transition frequency from 10 GHz to 6 GHz because it provides the most accurate account of exposure overall.

3.3. Local, 6-minute average, exposure restrictions up to the transition frequency (≤6 GHz)

Both guidelines use the same 6-minute averaged SAR basic restriction values to protect against excessive local temperature rise. However, whereas ICNIRP (1998) required SAR to be averaged over a 10-g contiguous tissue region, ICNIRP (2020) requires it to be averaged over a 10-g cubic region. The change in spatial averaging is to provide a better approximation of temperature rise.

As with ICNIRP (1998), ICNIRP (2020) provides different exposure limits for different body regions for frequencies below the transition region. However, there are subtle differences in how these body regions are defined. From a practical compliance perspective, the main difference is that the pinna is treated as being similar to other superficial tissue (such as the skin), rather than treating it as tissue requiring more stringent limitation, such as the brain. This is taken into account when setting the exposure restrictions for the Head and Torso, and the Limbs in order to simplify the exposure assessment: detail of the exposed tissue type does not need to be considered, only whether the exposure is of the Head and Torso, or of the Limbs.

3.4. Local, 6-minute average, exposure restrictions above the transition frequency (>6 GHz)

There are a few changes in the protection system for local exposure above 6 GHz.

First, whereas ICNIRP (1998) used the quantity 'incident power density', ICNIRP (2020) uses 'absorbed power density'. This is because the latter is a measure of exposure of the body, and thus satisfies the intent of a 'basic restriction', whereas the former is not a measure of exposure of the body because up to 50% of incident power density is reflected away from the body.

Second, whereas ICNIRP (1998) averaged over a 20-cm^2 region, ICNIRP (2020) requires averaging over a 4-cm^2 region (and in some situations a 1-cm^2 region). This 4-cm^2 averaging area matches the face of the averaging volume (10 g) of SAR, and provides a consistent transition at 6 GHz (see Section 3.3). This change also ensures that an allowable exposure over 20-cm^2 cannot be focused into a small region and increase temperature excessively. For example, for a restriction based on a 20-cm^2 averaging area, a homogeneous exposure over a 4-cm^2 region can be 5 times higher than if averaged over the entire 20-cm^2 region.

Third, to account for highly focused beams that may occur above 30 GHz, ICNIRP (2020) has also incorporated a 1-cm^2 restriction for frequencies >30 GHz; although the degree of focus increases continuously with frequency, equivalent restrictions are not set below 30 GHz because the beams are not 'sufficiently' focused to cause harm there. Note that the second and third point are particularly relevant for ensuring safety with future technologies, such as 5G.

Fourth, whereas ICNIRP (1998) reduced the averaging time with increasing frequency, this method is not used in ICNIRP (2020) because it provides a poorer prediction of temperature rise than is provided by the additional 'brief exposure restriction' that has been introduced in ICNIRP (2020); described in Section 3.5.

Fifth, the value of the basic restriction for EMFs >6 GHz (now the absorbed instead of the incident power density) has been set to provide equivalent maximum exposures in the body above and below 6 GHz. This results in a higher numerical basic restriction value for EMFs >6 GHz than in ICNIRP (1998). However, due to the use of a 4-cm^2 averaging area in the present guidelines (see Point 2 above), as opposed to 20-cm^2 in ICNIRP (1998), the peak exposure in the body for EMFs >6 GHz is now lower than was the case in the ICNIRP (1998) guidelines.

3.5. Restrictions for brief (<6-minute), local exposures

Brief, intense RF EMF exposures can raise local tissue temperature excessively, even if the average power over 6 minutes does not exceed the 6-minute average restrictions. This is particularly relevant for frequencies above 30 GHz, but it can also occur down to 400 MHz. Accordingly, ICNIRP (2020) provides additional restrictions to ensure that exposures over brief intervals do not result in excessive temperature rises. These restrictions are set as a function of exposure duration, and are applicable to both continuous (e.g. sinusoidal) and discontinuous (e.g. pulsed) RF EMF. As excessive temperature rise cannot occur in this manner below 400 MHz, these restrictions have only been implemented for EMF frequencies above 400 MHz.

From >400 MHz to 6 GHz, this restriction is given in terms of specific energy absorption (SA), and above 6 GHz it is given in terms of absorbed energy density (U_{ab}). These restrictions will ensure that new and future technologies utilising higher RF EMF frequencies, such as 5G, will not result in excessive temperature rise due to brief exposures.

3.6. Microwave hearing effect

Sub-millisecond pulses of RF EMF can result in audible sound. This occurs due to thermo-elastic tissue expansion resulting from very small (circa 0.00001°C) temperature rises, which is detected by sensory cells in the cochlea via the same processes involved in normal hearing. ICNIRP (1998) set a restriction to avoid the possibility of this auditory phenomenon. However, as this represents a sensory phenomenon, with no evidence that it would adversely affect health, this restriction is not used in the ICNIRP (2020) guidelines. Note that the brief exposure restrictions, described in Section 3.5 above, will protect against RF EMF pulses that are sufficiently intense to adversely affect health.

3.7. Nerve stimulation restrictions (100 kHz to 10 MHz)

ICNIRP (2020) has not re-evaluated the ICNIRP (2010) basic restrictions that were designed to protect against nerve stimulation. These occur within the 100 kHz to 10 MHz range, where both nerve stimulation and heating effects can be present. Instead, the ICNIRP (2010) basic restrictions for nerve stimulation have been added to the ICNIRP (2020) basic restrictions for all other potential adverse health effects, to provide a complete set of basic restrictions that covers the entire 100 kHz to 300 GHz EMF frequency range. As the ICNIRP (2010) guidelines have already updated the ICNIRP (1998) nerve stimulation-related basic restrictions from 100 kHz to 10 MHz, it follows that the ICNIRP (2020) guidelines also differ from ICNIRP (1998) in this respect.

4. Technical changes to the reference levels

4.1. Additional reference levels

ICNIRP (1998) provided reference levels for continuous whole-body exposures. This is relevant, for example, when assessing compliance in the community related to RF EMF emissions from devices such as mobile phone base stations. However, those reference levels did not cover all of the types of basic restriction. ICNIRP (2020) provides reference levels corresponding to all the basic restrictions. This allows a simpler means of assessing compliance with all the basic restrictions. However, note that due to complexities relating to the near- and far-field distinctions, there will still be situations where it is not possible to use reference levels; these situations are specified in the guidelines.

4.2. Removal of reference levels

ICNIRP (1998) included whole-body reference levels, specified in terms of E-field, H-field and power density, above 10 GHz. However, as E-field and H-field values do not always provide a good estimate of the basic restriction values above approximately 2 GHz, E-field and H-field values are not used in ICNIRP (2020) for whole body reference levels above 2 GHz.

ICNIRP (1998) included reference levels for contact currents. Contact currents occur when a conducting object redirects RF EMFs to a person through physical contact, which can increase the SAR in tissue above the basic restrictions. Accordingly, it can be useful to have a reference level to avoid exceeding the basic restrictions due to contact currents. As described in ICNIRP (2020), it is not possible to provide such a reference level due to the need to account for a variety of parameters that cannot be routinely specified in advance. Because of this, ICNIRP (2020) no longer provides contact current reference levels. Instead of reference levels, ‘guidance’ has been provided to help inform those responsible for occupational RF EMF exposures, to assist them in ensuring that this hazard is understood, and accounted for in an appropriate health and safety program.

4.3. Greater specification of compliance rules

ICNIRP (1998) specified reference levels primarily for electromagnetic fields within the far-field zone, but also allowed those reference levels to be used in the near-field zone. However, particularly with the introduction of additional reference levels to match each of the basic restrictions, there are complexities involved with measuring the EMFs within the near-field zones. Accordingly, reference levels have been specified with different requirements for EMFs within the far-field zone, radiative near-field zone, and reactive near-field zone. Further, the degree to which the reference levels adequately correspond to the basic restrictions is also affected by other factors that are beyond the scope of the ICNIRP (2020) guidelines. As a result, precise specification of the far-field, radiative near-field and reactive near-field zones needs to be considered 'in conjunction with' other important characteristics of the exposure scenario, such as antenna shape and size. Accordingly, it is now specified that input from a technical standards body is required for precise specification of near- and far-field zones so as to ensure concordance between the reference levels and basic restrictions.

It is important to note that in some exposure scenarios, EMF levels are not sufficiently informative to ensure that reference levels will correspond to the basic restrictions. In such cases, compliance with the basic restrictions is required; reference levels cannot be used to verify compliance. This is now specified clearly in ICNIRP (2020). For example, for EMFs above 2 GHz within the reactive near-field zone, such as those emanating from many mobile phone handsets and measured close to the device, reference levels cannot be used to demonstrate compliance.

4.4. Differences in reference level values

As described above, ICNIRP (2020) has introduced a range of new reference level categories, and so these provide reference level values that were not in ICNIRP (1998). These are not discussed further.

For ICNIRP (1998) there was limited research available below 30 MHz for ICNIRP (1998) to specify the reference levels. Accordingly, reference levels were set very conservatively. The ICNIRP (2010) low frequency guidelines, which included reference levels for EMF frequencies up to 10 MHz, reduced the electric and increased the magnetic field reference levels from 100 kHz to 10 MHz, relative to ICNIRP (1998). These changes were based on relatively weak science, and in the case of the electric field, were operationally very limiting. However, research has now better determined the relations between basic restrictions and both the electric and magnetic field reference levels, and ICNIRP (2020) has updated these reference levels to incorporate our improved knowledge. This does not affect the basic restrictions, but as we now know that higher reference level values are needed to reach the basic restrictions, the reference levels have been increased accordingly. The result of this is that in the frequency range of 100 kHz to 30 MHz, E-field and H-field reference levels are higher in ICNIRP (2020) than in ICNIRP (1998). Further, whereas the E- and H-field reference levels increased with reducing frequency from 20 MHz in ICNIRP (1998), research has shown that to match the whole-body basic restrictions, this increase should start at 30 MHz. ICNIRP (2020) thus has a monotonous increase in both the E- and H-field reference level values with decreasing frequency, that begins at 30 MHz. These differences can be seen in Figure 1.

As can also be seen in Figure 1, there are no differences between the ICNIRP (1998) and ICNIRP (2020) whole body average reference level values above 30 MHz. However, as the rules for applying the reference levels differ between the two guidelines, the same reference level values will result in different magnitudes of exposure to a person. That is, ICNIRP (1998) did not specify separate reference level values for exposures in the far- and near-field zones, but instead allowed the far-field zone reference level values to be used for fields within the near-field zone. New scientific knowledge allowed rules to be set in ICNIRP (2020) for the application of reference levels in the near- and far-field separately. This will ensure that exposures within the near-field zone will not result in over-exposure. In addition, although ICNIRP (1998) allowed E-field and H-field to be used for whole-body average reference levels across the entire 100 kHz to 300 GHz frequency range, this method can potentially result in inaccuracies for frequencies above about 2 GHz within the near-field zone and so is not permitted within the new guidelines; measures of power density must be used instead.

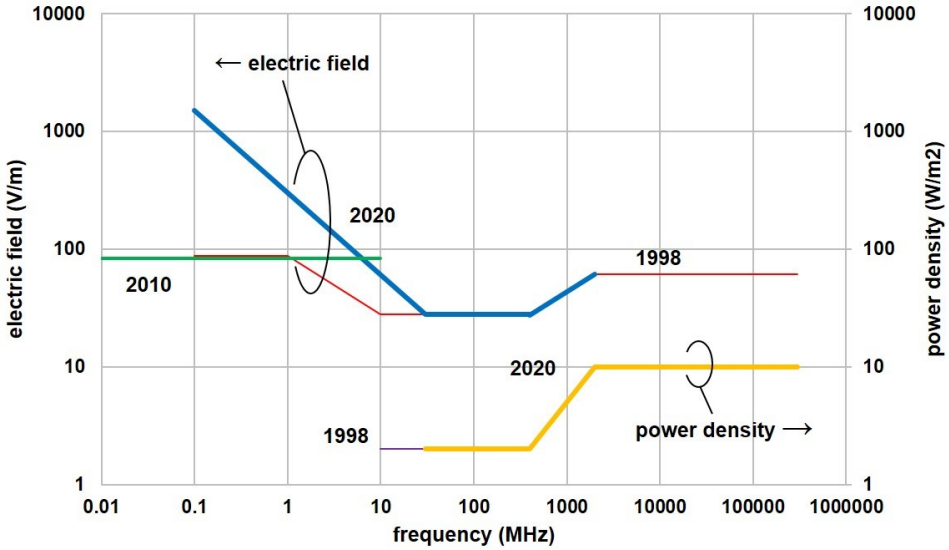

Figure 1. Whole body average reference levels for the general public for the ICNIRP (1998), ICNIRP (2010) and ICNIRP (2020) guidelines, for the 100 kHz to 300 GHz frequency range. Note that the units of the two y-axes (i.e. electric field and power density) are independent of each other.

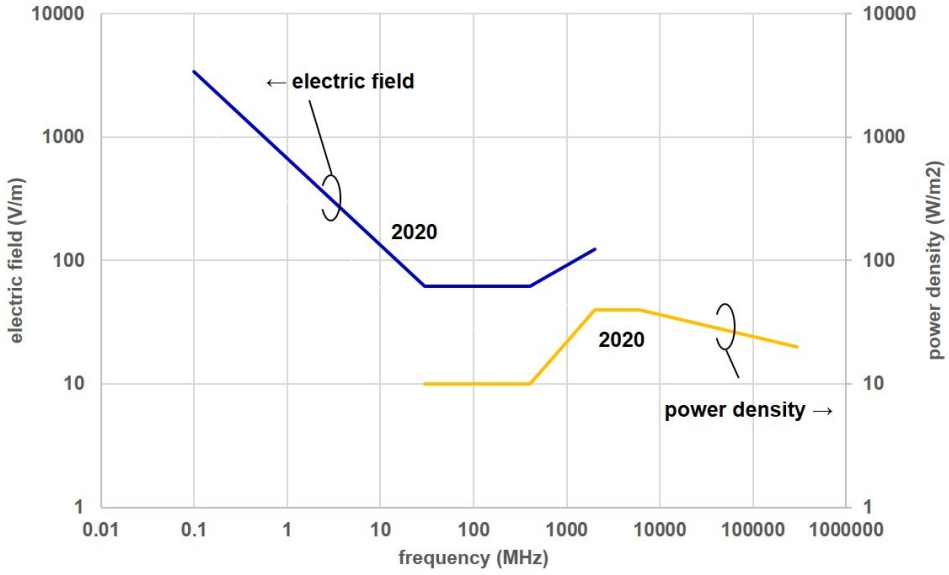

Figure 2. Reference levels for the general public applying to local exposures ≥6 min for the ICNIRP (2020) guidelines, for the 100 kHz to 300 GHz frequency range. Local exposure reference levels were not given in the ICNIRP (1998) and ICNIRP (2010) guidelines. Note that the units of the two y-axes (i.e. electric field and power density) are independent of each other.

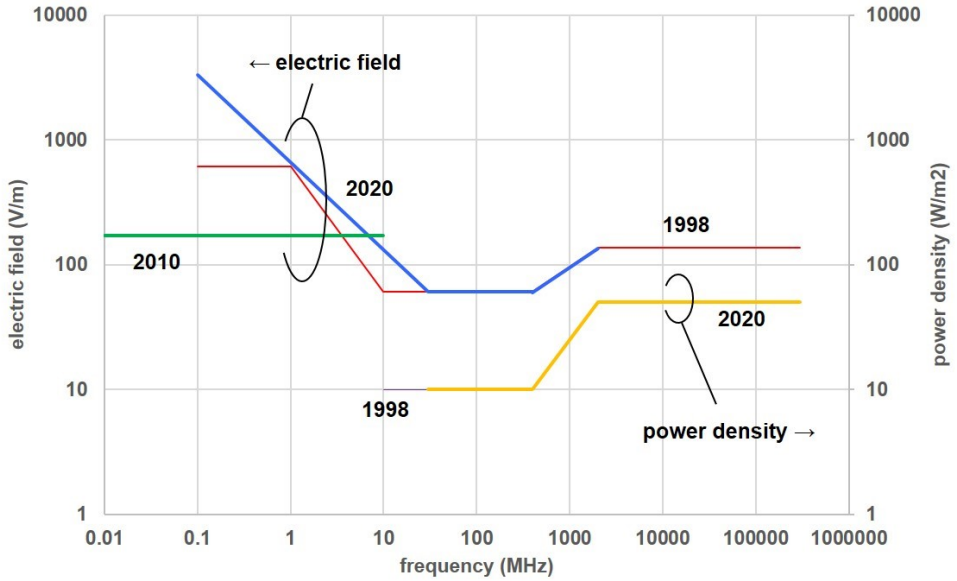

Figure 3. Whole body average reference levels for workers for the ICNIRP (1998), ICNIRP (2010) and ICNIRP (2020) guidelines, for the 100 kHz to 300 GHz frequency range. Note that the units of the two y-axes (i.e. electric field and power density) are independent of each other.

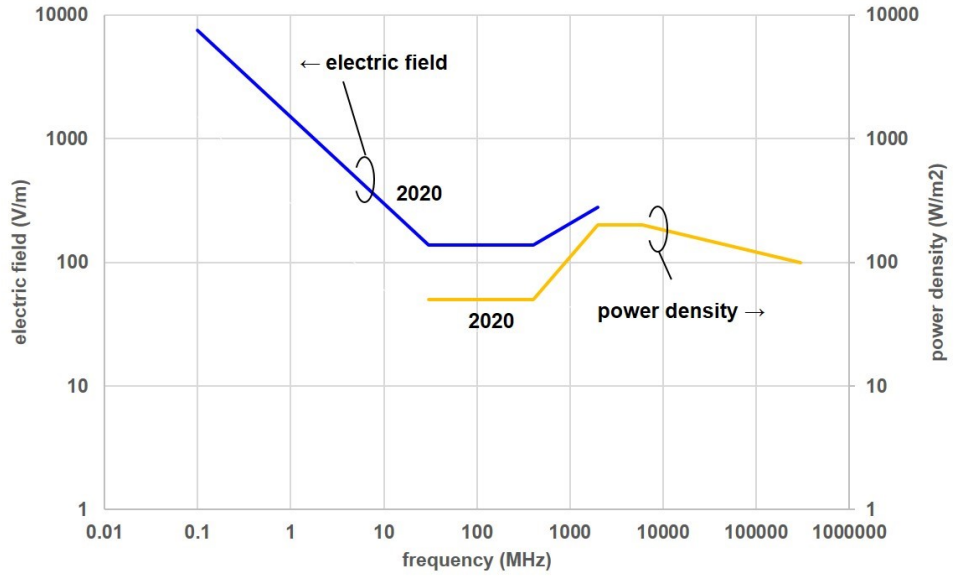

Figure 4. Reference levels for workers applying to local exposures ≥6 min for the ICNIRP (2020) guidelines, for the 100 kHz to 300 GHz frequency range. Local exposure reference levels were not given in the ICNIRP (1998) and ICNIRP (2010) guidelines. Note that the units of the two y-axes (i.e. electric field and power density) are independent of each other.