

**Draft***ICNIRP Guidelines***GUIDELINES FOR LIMITING EXPOSURE TO TIME-VARYING ELECTRIC,  
MAGNETIC AND ELECTROMAGNETIC FIELDS  
(100 kHz TO 300 GHz)****International Commission on Non-Ionizing Radiation Protection****1. INTRODUCTION**

The guidelines described here are for the protection of humans exposed to radiofrequency electromagnetic fields (EMFs) in the range 100 kHz to 300 GHz (hereafter ‘radiofrequency’). This publication replaces the radiofrequency part of the 1998 guidelines (ICNIRP 1998); ICNIRP has already published updated guidelines for the low-frequency part (ICNIRP 2010). Although these guidelines are based on the best science currently available, it is recognized that there may be limitations to this knowledge which could impact on the exposure restrictions. Accordingly, the guidelines will be periodically revised and updated as advances are made in the relevant scientific knowledge.

**2. PURPOSE AND SCOPE**

The main objective of this publication is to establish guidelines for limiting exposure to EMFs that will provide a high level of protection for all people against known adverse health effects from direct, non-medical exposures to both short- and long-term, continuous and discontinuous radiofrequency EMFs. Within this context, ‘direct’ refers to effects of radiofrequency EMF directly on tissue, rather than via an intermediate object. Medical procedures may utilize or alter EMF fields and result in direct effects on the body (e.g. radiofrequency ablation, hyperthermia). As medical procedures require potential harm to be weighed against intended benefits, ICNIRP treats exposure related to medical procedures (i.e. to patients, carers and comforters) as beyond the scope of these guidelines (for further information, see UNEP/WHO/IRPA, 1993). Similarly, volunteer research participants are deemed to be outside the scope of these guidelines, providing that an institutional ethics committee approves such participation following consideration of potential harms and benefits. Cosmetic procedures may also utilize radiofrequency EMFs. ICNIRP treats people exposed to radiofrequency EMF as a result of cosmetic treatments as subject to these guidelines, with any decisions as to potential exemptions the role of national regulatory bodies, which are better suited to weigh potential benefits and harms within the context of cultural norms. Radiofrequency EMF may also interfere with electrical equipment, which can affect health indirectly by causing equipment to malfunction. This is referred to as electromagnetic compatibility, and is outside the scope of these guidelines (for further information, see ISO14117 and IEC 60601-1-2).

### 42 3. PRINCIPLES FOR LIMITING RADIOFREQUENCY EXPOSURE

43 These guidelines specify quantitative EMF levels for safe personal exposure. Adherence to  
44 these levels is intended to protect people from all known harmful effects of radiofrequency  
45 EMF exposure. To determine these levels, ICNIRP first identified published scientific  
46 literature concerning effects of radiofrequency EMF exposure on biological systems, and  
47 established which of these were both harmful to human health<sup>1</sup>, and scientifically  
48 substantiated. This latter point is important because ICNIRP considers that, in general, reported  
49 effects need to be independently replicated, be of sufficient scientific quality and explicable  
50 more generally within the context of the scientific literature, in order to be taken as ‘evidence’  
51 and used for setting exposure restrictions. Within the guidelines, ‘evidence’ will be used within  
52 this context, and ‘substantiated effect’ used to describe reported effects that satisfy this  
53 definition of evidence.

54 For each substantiated effect, ICNIRP then identified the ‘adverse health effect threshold’; the  
55 lowest exposure level known to cause the health effect. These thresholds were derived to be  
56 strongly conservative for typical exposure situations and populations. Where no such threshold  
57 could be explicitly obtained from the radiofrequency health literature, or where evidence that is  
58 independent from the radiofrequency health literature has (indirectly) shown that harm can  
59 occur at levels lower than the ‘EMF-derived threshold’, ICNIRP set an ‘operational threshold’.  
60 These are based on more-general knowledge of the relation between the primary effect of  
61 exposure (e.g. heating) and health effect (e.g. pain), to provide an operational level with which  
62 to derive restriction values in order to attain an appropriate level of protection. Consistent with  
63 previous guidelines from ICNIRP, reduction factors were then applied to the resultant  
64 thresholds (or operational thresholds) to provide exposure limit values. Reduction factors  
65 account for biological variability in the population, variance in baseline conditions (e.g. tissue  
66 temperature), variance in environmental factors (e.g. air temperature, clothing), dosimetric  
67 uncertainty associated with deriving exposure values, uncertainty associated with the health  
68 science, and as a conservative measure more generally.

69 The exposure limit values are referred to as ‘basic restrictions’, and relate to physical quantities  
70 inside an exposed body that are closely related to radiofrequency-induced adverse health  
71 effects. These quantities cannot be easily measured, and so quantities that are more easily  
72 evaluated, termed ‘reference levels’, have been derived from the basic restrictions to provide a  
73 more-practical means of demonstrating compliance with the guidelines. Reference levels have  
74 been derived to provide an equivalent degree of protection to the basic restrictions, and thus an  
75 exposure is taken to be compliant with the guidelines if it is shown to be below either the  
76 relevant basic restrictions or relevant reference levels. Note that the relative concordance  
77 between exposures resulting from basic restrictions and reference levels may vary depending  
78 on a range of factors. As a conservative step, reference levels have been derived such that  
79 under worst-case exposure conditions (which are highly unlikely to occur in practice), they will  
80 result in similar exposures to those specified by the basic restrictions. It follows that in the vast  
81 majority of cases the reference levels will result in substantially lower exposures than the  
82 corresponding basic restrictions allow. See Section 5.2 for further details.

83 The guidelines differentiate between occupationally-exposed individuals and members of the  
84 general public. Occupationally-exposed individuals are defined as healthy adults who are  
85 exposed under controlled conditions associated with their occupational duties, trained to be  
86 aware of potential radiofrequency EMF risks and to employ appropriate harm-mitigation

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<sup>1</sup> Note that the World Health Organization (2006) definition of ‘health’ is used here. Specifically, “health is a state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity”.

87 measures, and who have the capacity for such awareness and harm-mitigation response; it is  
88 not sufficient for a person to merely be a worker. The general public is defined as individuals  
89 of all ages and of differing health statuses, which may include particularly vulnerable groups or  
90 individuals, and who may have no knowledge of or control over their exposure to EMF. These  
91 differences suggest the need to include more stringent restrictions for the general public, as  
92 members of the general public would not be suitably trained to mitigate harm, or may not have  
93 the capacity to do so. Occupationally-exposed individuals are not deemed to be at greater risk  
94 than the general public, providing that appropriate screening and training is provided to  
95 account for all known risks. Note that a fetus is here defined as a member of the general public,  
96 regardless of exposure scenario, and is subject to the general public restrictions.

97 As can be seen above, there are a number of steps involved in deriving ICNIRP's guidelines.  
98 ICNIRP adopts a conservative approach to each of these steps in order to ensure that its limits  
99 would remain protective even if exceeded by a substantial margin. For example the choice of  
100 adverse health effects, presumed exposure scenarios, application of reduction factors and  
101 derivation of reference levels are all conducted conservatively. The degree of precaution in the  
102 exposure levels is thus greater than may be suggested by considering only the reduction  
103 factors, which represent only one conservative element of the guidelines. ICNIRP considers  
104 that the derivation of limits is sufficiently conservative to make additional precautionary  
105 measures unnecessary.

## 106 **4. SCIENTIFIC BASIS FOR LIMITING HIGH FREQUENCY EXPOSURE**

### 107 **4.1. QUANTITIES, UNITS AND INTERACTION MECHANISMS**

108 A brief overview of the electromagnetic quantities and units employed in this document, as  
109 well as the mechanisms of interaction of these with the body, is provided here. A more detailed  
110 description of the dosimetry relevant to the guidelines is provided in Appendix A.

111 Radiofrequency EMFs consist of rapidly oscillating electric and magnetic fields; the number of  
112 oscillations per second is referred to as 'frequency', and is described in units of hertz (Hz). As  
113 the field propagates away from a source, it transfers power from its source, described in units  
114 of watts (W), which is equivalent to joules (J, a measure of energy) per second. When the field  
115 impacts upon material, it interacts with the atoms and molecules in that material. When  
116 radiofrequency EMF reaches a biological body, some of its power is reflected away from the  
117 body, and some is transmitted into it. This results in complex patterns of fields inside the body  
118 that are heavily dependent on the EMF source and frequency, as well as on the physical  
119 properties and dimensions of the body. These internal fields are referred to as induced electric  
120 fields ( $\mathbf{E}$ , measured in volts per meter;  $\text{V m}^{-1}$ ), and they can affect the body in different ways  
121 that are potentially relevant to health.

122 Firstly, the induced electric field in the body exerts force on both polarized molecules (mainly  
123 water molecules) and on free moving charged particles such as electrons and ions. In both  
124 cases the EMF energy is converted to movement energy, forcing the polarized molecules to  
125 rotate and charged particles to move as a current. As the polarized molecules rotate and  
126 charged particles move, they typically interact with other polarized molecules and charged  
127 particles, causing the movement energy to be converted to heat. This heat can affect health in a  
128 range of ways. Secondly, if the induced electric field is strong and brief enough, it can exert  
129 electrical forces that are sufficient to stimulate nerves, or to cause dielectric breakdown of  
130 biological membranes, as occurs during direct current (DC) electroporation (Mir, 2008).

131 From a health risk perspective we are generally interested in how much EMF power is  
132 absorbed by biological tissue, as this is responsible for the heating effects described above.

133 This is typically described as a function of a relevant dosimetric quantity. For example, below  
 134 6 GHz, where EMF penetrates deep into tissue (and thus requires depth to be considered), it is  
 135 useful to describe this in terms of ‘specific absorption rate’ (SAR), which is the power  
 136 absorbed per unit mass ( $\text{W kg}^{-1}$ ). Conversely, above 6 GHz, where EMF is absorbed more  
 137 superficially (making depth less relevant), it is useful to describe exposure in terms of  
 138 transmitted power density ( $\mathbf{S}_{\text{tr}}$ ), which is the power absorbed per unit area ( $\text{W m}^{-2}$ ). In these  
 139 guidelines SAR is specified over different masses to better match particular adverse health  
 140 effects;  $\text{SAR}_{10\text{g}}$  represents the power absorbed (per kg) over a 10-g cubical mass, and whole  
 141 body average SAR represents power absorbed (per kg) over the entire body. Similarly,  
 142 transmitted power density is specified over different areas due to such factors as exposure  
 143 duration and EMF frequency. In some situations the rate of energy deposition (power) is less  
 144 relevant than the total energy deposition. This may be the case for brief exposures where there  
 145 is not sufficient time for heat diffusion to occur. In such situations, specific absorption (SA, in  
 146  $\text{J kg}^{-1}$ ) and transmitted energy density ( $\mathbf{H}_{\text{tr}}$ , in  $\text{J m}^{-2}$ ) are used, for EMF below and above 6 GHz  
 147 respectively. SAR,  $\mathbf{S}_{\text{tr}}$ , SA and  $\mathbf{H}_{\text{tr}}$  are the quantities used in these guidelines to specify the  
 148 basic restrictions.

149 As the quantities used to specify basic restrictions can be difficult to measure, quantities that  
 150 are more easily evaluated, termed reference levels, are also specified. The reference level  
 151 quantities relevant to these guidelines are electric field ( $\mathbf{E}$ ) and magnetic field ( $\mathbf{H}$ ), as described  
 152 above, as well as incident power density ( $\mathbf{S}_{\text{inc}}$ ) and equivalent incident power density ( $\mathbf{S}_{\text{eq}}$ ),  
 153 both measured outside the body and described in units of watts per square-meter ( $\text{W m}^{-2}$ ), and  
 154 electric current inside the body,  $I$ , described in units of ampere (A).

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156 **Table 1.** Quantities and corresponding SI units used in these guidelines

Quantity	Symbol	Unit
Current	$I$	ampere (A)
Electric field strength	$\mathbf{E}$	volt per meter ( $\text{V m}^{-1}$ )
Equivalent incident power density	$\mathbf{S}_{\text{eq}}$	watt per square meter ( $\text{W m}^{-2}$ )
Frequency	$f$	hertz (Hz)
Incident power density	$\mathbf{S}_{\text{inc}}$	watt per square meter ( $\text{W m}^{-2}$ )
Magnetic field strength	$\mathbf{H}$	ampere per meter ( $\text{A m}^{-1}$ )
Specific energy absorption	SA	joule per kilogram ( $\text{J kg}^{-1}$ )
Specific energy absorption rate	SAR	watt per kilogram ( $\text{W kg}^{-1}$ )
Transmitted energy density	$\mathbf{H}_{\text{tr}}$	radiant exposure ( $\text{J m}^{-2}$ )
Transmitted power density	$\mathbf{S}_{\text{tr}}$	watt per square meter ( $\text{W m}^{-2}$ )
Time	$t$	second (s)

## 157 **RADIOFREQUENCY EMF HEALTH RESEARCH**

158 In order to set safe limits, ICNIRP first determined whether there was evidence that  
159 radiofrequency EMF impaired health, and for each adverse effect that was substantiated,  
160 determined (where available) both the mechanism of interaction and the minimum exposure  
161 required to cause harm. This information was obtained primarily from major international  
162 reviews of the literature on radiofrequency EMF and health, including an in-depth review from  
163 the WHO on radiofrequency EMF exposure and health that will be released as a Technical  
164 Document in the near future (World Health Organization, 2014), and SCENIHR (2015). These  
165 reports have reviewed an extensive body of literature, ranging from experimental research to  
166 epidemiology. To complement those reports, ICNIRP also considered research published since  
167 those reviews. A brief summary of this literature is provided in Appendix B.

168 As described in Appendix B, radiofrequency EMF can affect the body via three primary  
169 biological effects: nerve stimulation, membrane permeabilization, and temperature elevation.  
170 In addition to these, knowledge concerning relations between these primary biological effects  
171 and health, independent of the radiofrequency EMF literature, was also evaluated. ICNIRP  
172 considers this appropriate given that the vast majority of radiofrequency EMF health research  
173 has been conducted using exposures substantially lower than those shown to produce adverse  
174 health effects, with relatively little research addressing adverse health effect thresholds  
175 themselves. Thus it is possible that the radiofrequency health literature may not be sufficiently  
176 comprehensive to ascertain thresholds. Conversely, where a more-extensive literature is  
177 available that clarifies the relation between health and the primary biological effects, this can  
178 be useful for setting guidelines. For example, if the thermal physiology literature demonstrated  
179 that local temperature elevations of a particular magnitude caused harm, but radiofrequency  
180 exposure known to produce a similar temperature elevation had not been evaluated for harm,  
181 then it would be reasonable to also consider this additional thermal physiology literature.  
182 ICNIRP refers to thresholds derived from such additional literature as *operational* adverse  
183 health effect thresholds.

184 It is important to note that ICNIRP only uses operational thresholds to set restrictions where  
185 they are lower (more conservative) than those demonstrated to affect health in the  
186 radiofrequency literature, or where the radiofrequency literature does not provide sufficient  
187 evidence to deduce an adverse health effect threshold. For the purpose of determining  
188 thresholds, evidence of adverse health effects arising from all exposures is considered,  
189 including those referred to as ‘low-level’ and ‘non-thermal’, and including those where  
190 mechanisms have not yet been elucidated.

### 191 **4.3. THRESHOLDS FOR RADIOFREQUENCY EMF-INDUCED HEALTH EFFECTS**

#### 192 **4.3.1. NERVE STIMULATION**

193 Exposure to EMF can induce electric fields within the body, which for frequencies up to 10  
194 MHz can stimulate nerves (Saunders and Jeffreys, 2007); this is not known to occur *in vivo* at  
195 frequencies higher than approximately 10 MHz. The effect of this stimulation varies as a  
196 function of frequency, and is typically reported as a ‘tingling’ sensation for frequencies around  
197 100 kHz (where peak field is most relevant). As frequency increases, heating effects  
198 predominate and the likelihood of nerve stimulation decreases; at 10 MHz the electric field is  
199 typically described as ‘warmth’. Nerve stimulation by induced electric fields is protected by the  
200 ICNIRP low frequency guidelines (2010), and is not discussed further here.

### 201 4.3.2. MEMBRANE PERMEABILIZATION

202 When (low frequency) EMF is pulsed, the power is distributed across a range of frequencies,  
203 which can include radiofrequency EMF (Joshi and Schoenbach, 2010). If the pulse is  
204 sufficiently intense and brief, exposure to the resultant EMF may cause cell membranes to  
205 become permeable, which in turn can lead to other cellular changes. However, there is no  
206 evidence that the radiofrequency spectral component from an EMF pulse (without the low-  
207 frequency component) is sufficient to cause this permeability. The restrictions on nerve  
208 stimulation in the ICNIRP (2010) guidelines provide adequate protection against the low  
209 frequency components, so additional protection from the resultant radiofrequency EMF is not  
210 necessary. Membrane permeability has also been shown to occur with 18 GHz continuous  
211 wave exposure (e.g. Nguyen et al., 2015). This has only been demonstrated *in vitro*, and  
212 requires very high exposure levels (circa 5 kW kg<sup>-1</sup>) that far exceed those required to cause  
213 thermally-induced harm (see Section 4.3.3). Therefore there is also no need to specifically  
214 protect against this effect, as restrictions designed to protect against smaller temperature  
215 elevations will also protect against this.

### 216 4.3.3. TEMPERATURE ELEVATION

217 Radiofrequency EMFs can generate heat in the body. As heat can affect health, it is important  
218 that heat generated by EMF is kept to a safe level. However, as can be seen from Appendix B,  
219 there is a dearth of radiofrequency exposure research using sufficient power to cause heat-  
220 induced health effects. Of particular note is that although exposures (and resultant temperature  
221 rises) have occasionally been shown to cause severe harm, the literature lacks concomitant  
222 evidence of the highest exposures that do not cause harm. For very low exposure levels (such  
223 as within the ICNIRP (1998) basic restrictions) there is extensive evidence that the amount of  
224 heat generated is not sufficient to cause harm, but for exposure levels above those of the  
225 ICNIRP (1998) basic restriction levels, yet below those shown to produce harm, there is still  
226 uncertainty. Where there is good reason to expect health impairment at temperatures lower than  
227 those shown to impair health via radiofrequency EMF exposure, ICNIRP uses those lower  
228 temperatures to base limits on.

229 It is important to note that these guidelines restrict radiofrequency EMF exposure to limit  
230 temperature increase ( $\Delta T$ ) rather than absolute temperature, whereas health effects are  
231 primarily related to absolute temperature. This strategy is used because it is not feasible to limit  
232 absolute temperature, which is dependent on many factors that are outside the scope of these  
233 guidelines, such as environmental temperature, clothing and work rate. This means that if  
234 exposure caused a given temperature increase, this could improve, not affect, or impair health  
235 depending on the prevailing conditions. For example, mild heating can be pleasant if a person  
236 is cold, but unpleasant if they are already very hot. The restrictions are therefore set to avoid  
237 significant increase in temperature, where 'significant' is considered in light of both potential  
238 harm and normal physiological temperature variation. These guidelines differentiate between  
239 steady-state temperature elevations (where temperature increases slowly, allowing time for  
240 temperature to dissipate over a larger tissue mass and for thermoregulatory processes to  
241 counter temperature rise), and brief temperature elevations (where there may not be sufficient  
242 time for temperature to dissipate, which can cause larger temperature elevations in small  
243 regions given the same absorbed radiofrequency power). This distinction suggests the need to  
244 account for steady-state and brief exposure durations separately.

### 245 4.3.3.1. STEADY-STATE TEMPERATURE RISE

#### 246 4.3.3.1.1. BODY CORE TEMPERATURE

247 Body core temperature refers to the temperature deep within the body, such as in the abdomen  
248 and brain, and varies substantially as a function of such factors as gender, age, time of day,  
249 work rate, environmental conditions and thermoregulation. For example, although the mean  
250 body core temperature is approximately 37 °C (and within the ‘normothermic’ range<sup>2</sup>), this  
251 typically varies over a 24-hour period to meet physiological needs, with the magnitude of the  
252 variation as large as 1 °C (Reilly et al., 2007). As thermal load increases, thermoregulatory  
253 functions such as vasodilation and sweating can be engaged to restrict body core temperature  
254 elevation. This is important because a variety of health effects can occur beyond this range  
255 (>38 °C, termed ‘hyperthermia’). Although most health effects induced by mild hyperthermia  
256 resolve readily and have no lasting effects, risk of accident increases with hyperthermia  
257 (Ramsey et al, 1983), and at body core temperatures > 40 °C it can lead to heat stroke, which  
258 can be fatal (Cheshire, 2016).

259 Detailed guidelines are available for minimising risk associated with hyperthermia within the  
260 occupational setting (ACGIH, 2017). These aim to modify work environments so as to keep  
261 body core temperature within +1 °C of normothermia, and require substantial knowledge of  
262 each particular situation due to the range of variables that can affect it. As described in  
263 Appendix B, body core temperature rise due to radiofrequency EMF that results in harm is  
264 only seen where temperature greatly exceeds +1 °C (e.g. > +5 °C in rats; Jauchem and Frei,  
265 1997), with no clear evidence of the adverse health effect threshold. Due to the limited  
266 literature available ICNIRP has adopted a conservative temperature rise value as the  
267 operational adverse health effect threshold (the 1 °C rise of ACGIH, 2017). It is important to  
268 note that even though body core temperature increases at the operational adverse health effect  
269 threshold (+ 1°C) can result in significant physiological changes, this can be part of the body’s  
270 normal thermoregulatory response and within the normal physiological range, and thus does  
271 not *in itself* represent an adverse health effect.

272 Recent theoretical modelling and generalization from experimental research across a range of  
273 species predicts that exposures resulting in a whole body average SAR of approximately 6 W  
274 kg<sup>-1</sup>, within the 100 kHz – 6 GHz range, over at least a 1-hour interval at moderate ambient  
275 temperature (28 °C), is required to induce a 1 °C body core temperature rise in human adults; a  
276 substantially higher SAR is required to reach this temperature rise in children due to their  
277 more-efficient heat dissipation (Hirata et al., 2013). However, given the limited measurement  
278 data available, ICNIRP has adopted a conservative position and uses 4 W kg<sup>-1</sup>, averaged over  
279 30 minutes, as the radiofrequency EMF exposure level corresponding to a body core  
280 temperature rise of 1 °C. As a comparison, a human adult generates a total of approximately 1  
281 W kg<sup>-1</sup> at rest (Weyand et al., 2009), nearly 2 W kg<sup>-1</sup> standing, and 12 W kg<sup>-1</sup> running  
282 (Teunissen et al., 2007).

283 As EMF frequency increases, exposure of the body and the resultant heating becomes more  
284 superficial, and above about 6 GHz this heating occurs predominantly within the skin. For  
285 example, 86% of the power at 6 and 300 GHz is absorbed within 8 and 0.2 mm of the surface  
286 respectively (Sasaki, 2017). Heat is more easily removed from the body when superficial than  
287 deep in the body because it is easier for the heat energy to transfer to the environment through  
288 convection; this is why basic restrictions to protect against body core temperature elevation

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<sup>2</sup> ‘Normothermia’ refers to the thermal state within the body whereby active thermoregulatory processes are not engaged to either increase or decrease body core temperature.



289 have traditionally been limited to frequencies below 10 GHz (e.g. ICNIRP 1998). However,  
290 recent research has shown that EMF frequencies beyond 300 GHz (e.g. infrared) can increase  
291 body core temperature beyond the 1 °C operational adverse health effect threshold described  
292 above (Brockow et al., 2007). This is because infrared, as well as lower frequencies within the  
293 scope of the present guidelines, cause heating within the dermis, and the extensive vascular  
294 network within the dermis can transport this heat deep within the body. It is therefore  
295 appropriate to also protect against body core temperature elevation above 6 GHz.

296 ICNIRP is not aware of research that has assessed the effect of 6 – 300 GHz EMF on body core  
297 temperature, nor of research that has demonstrated that it is harmful. However, as a  
298 conservative measure, ICNIRP uses the 4 W kg<sup>-1</sup> corresponding to the operational adverse  
299 health effect threshold for frequencies up to 6 GHz, for the >6 – 300 GHz range as well. In  
300 support of this being a conservative value, it has been shown that 1257 W m<sup>-2</sup> (incident power  
301 density) infrared exposure to one side of the body results in a 1 °C body core temperature rise  
302 (Brockow et al, 2007). If we related this to the exposure of a 70 kg adult with an exposed  
303 surface area of 1 m<sup>2</sup> and no skin reflectance, this would result in a whole body exposure of  
304 approximately 18 W kg<sup>-1</sup>, which is far higher than the 4 W kg<sup>-1</sup> taken here for EMF below 6  
305 GHz to represent the exposure corresponding to a 1 °C body core temperature rise. This is  
306 viewed as additionally conservative given that the Brockow et al. study reduced heat  
307 dissipation via a thermal blanket, which underestimates the exposure required to increase body  
308 core temperature under typical conditions.

#### 309 4.3.3.1.2. LOCAL TEMPERATURE

310 In addition to body core temperature, excessive localised heating can cause pain and thermal  
311 damage. There is an extensive literature showing that skin contact with temperatures below 42  
312 °C for extended periods will not cause pain or damage cells (e.g. Defrin et al., 2006). As  
313 described in Appendix B, this is consistent with the limited data available for radiofrequency  
314 EMF heating of the skin (e.g. Walters et al., 2000 reported a pain threshold of 43 °C using 94  
315 GHz exposure), but fewer data are available for heat sources that penetrate beyond the  
316 protective epidermis and to the heat-sensitive epidermis/dermis interface. However, there is  
317 also a substantial body of literature assessing thresholds for tissue damage which shows that  
318 damage can occur at tissue temperatures > 41-43 °C, with damage likelihood and severity  
319 increasing as a function of time at such temperatures (e.g. Dewhirst et al. 2003, Yarmolenko et  
320 al. 2011, van Rhoon et al. 2013).

321 The current guidelines treat radiofrequency EMF exposure that results in local temperatures of  
322 41 °C or greater as potentially harmful. As body temperature varies as a function of body  
323 region, ICNIRP treats exposure to different regions separately. Corresponding to these regions,  
324 these guidelines define two sets of tissue types which, based on their temperature under  
325 normothermal conditions, are assigned different operational health effect thresholds; ‘Type-1’  
326 tissue, which typically has a lower thermo-normal temperature (all tissues in the upper arm,  
327 forearm, hand, thigh, leg, foot, pinna and the cornea, anterior chamber and iris of the eye,  
328 epidermal, dermal, fat, muscle and bone tissue), and ‘Type-2’ tissue, which typically has a  
329 higher normothermal temperature (all tissues in the head, eye, abdomen, back, thorax and  
330 pelvis, excluding those defined as Type-1 tissue). The normothermal temperature of Type 1  
331 tissue is typically < 33-36 °C, and that of Type-2 tissue < 38-38.5 °C (DuBois 1941; Aschoff &  
332 Wever, 1958; Arens and Zhang, 2006; Shafahi & Vafai, 2011). These values were used to  
333 define operational thresholds for local heat-induced health effects; adopting 41 °C as  
334 potentially harmful, these guidelines take a conservative approach and treat radiofrequency  
335 EMF-induced temperature rises of 5 °C and 2 °C, within Type-1 and Type-2 tissue  
336 respectively, as operational adverse health effect thresholds for local exposure. It is difficult to



337 set exposure limits as a function of the above tissue-type classification. ICNIRP thus defines  
338 two regions, and sets separate exposure limits, where relevant, for these regions; ‘Head and  
339 Torso’, comprising the head, eye, abdomen, back, thorax and pelvis, and the ‘Limbs’,  
340 comprising the upper arm, forearm, hand, thigh, leg and foot. Operational adverse health effect  
341 thresholds for each of these regions are set such that they do not result in temperature  
342 elevations of more than 5 °C and 2 °C, in Type-1 and Type-2 tissue respectively. As the limbs,  
343 by definition, do not contain any Type-2 tissue, the operational adverse health effect threshold  
344 for the limbs is always 5 °C.

345 The testes can be viewed as representing a special case, whereby reversible, graded, functional  
346 change can occur within normal physiological temperature variation if maintained over  
347 extended periods, with no apparent threshold. For example, spermatogenesis is reversibly  
348 reduced as a result of the 2 °C increase caused by normal activities such as sitting (relative to  
349 standing; Mieusset and Bujan, 1995). Thus it is possible that the operational threshold for  
350 Type-2 tissue may result in reversible changes to sperm function. However, there is currently  
351 no evidence that such effects are sufficient to impair health. Accordingly, ICNIRP views the  
352 operational threshold of 2 °C for Type-2 tissue, which is within the normal physiological range  
353 for the testes, as appropriate for the testes also. Note that the operational threshold for Type-2  
354 tissue, which includes the abdomen and thus potentially the fetus, is also consistent with  
355 protecting against the fetal temperature threshold of 2 °C for teratogenic effects in animals  
356 (Edwards et al, 2003; Ziskin & Morrissey, 2011).

357 Within the 100 kHz – 6 GHz EMF range, average SAR over 10 g provides an appropriate  
358 measure of the radiofrequency EMF-induced steady-state temperature rise within tissue. A 10 g  
359 mass is used because, although there can initially be EMF-induced temperature heterogeneity  
360 within that mass, heat diffusion rapidly distributes the thermal energy to a much larger volume  
361 that is well-represented by a 10 g cubic mass (Hirata and Fujiwara, 2009). In specifying  
362 exposures that correspond to the operational adverse health effect thresholds, ICNIRP thus  
363 specifies an average exposure over a 10 g cubic mass, such that the exposure will keep the  
364 Type-1 and Type-2 tissue temperature elevations, to below 5 and 2 °C respectively. Further,  
365 ICNIRP assumes realistic exposures (such as from radio-communications sources). This  
366 method provides for higher exposures in the limbs than in the head and torso. A SAR<sub>10g</sub> of at  
367 least 20 W kg<sup>-1</sup> is required to exceed the operational adverse health effect thresholds in the  
368 Head and Torso, and 40 W kg<sup>-1</sup> in the Limbs, over an interval sufficient to produce a steady  
369 state temperature (from a few minutes to 30 minutes). This time interval is operationalized as a  
370 6-minute average as it closely matches the thermal time constant for local exposure.

371 Within the >6 – 300 GHz range, EMF energy is deposited predominantly in superficial tissues;  
372 this makes SAR<sub>10g</sub>, which includes deeper tissues, less relevant to this frequency range.  
373 Conversely, transmitted power density ( $S_{tr}$ ) provides a measure of the power absorbed in tissue  
374 that closely approximates the superficial temperature rise (Hashimoto et al., 2017). From 6 to  
375 10 GHz there may still be significant absorption in the subcutaneous tissue. However, as the  
376 maximum and thus worst-case temperature elevation from >6 to 300 GHz is close to the skin,  
377 exposure that will restrict temperature elevation to below the operational adverse health effect  
378 threshold for Type-1 tissue (5 °C) will also restrict temperature elevation to below the Type-2  
379 tissue threshold (2 °C). Note that there is uncertainty with regard to the precise frequency for  
380 the change from SAR to transmitted power density. 6 GHz was chosen because at that  
381 frequency, most of the absorbed power is within the cutaneous tissue, which is within the upper  
382 half of a 10 g SAR cubic volume (that is, it can be represented by the 2.15 x 2.15 cm surface of  
383 the cube). Indeed recent thermal modeling and analytical solutions suggest that the averaging  
384 area of 4 cm<sup>2</sup> (2 cm × 2 cm) provides a good estimate of local maximum temperature elevation  
385 due to radiofrequency exposure between 6 and 30 GHz (Hashimoto et al., 2017; Foster et al.,

386 2017). As frequency increases further, the averaging area needs to be reduced to account for  
387 the possibility of smaller beam diameters, such that it is 1 cm<sup>2</sup> from approximately 30 GHz to  
388 300 GHz. Although the ideal averaging area would therefore gradually change from 4 to 1 cm<sup>2</sup>  
389 as frequency increases from 6 to 300 GHz, ICNIRP uses a step function (4 cm<sup>2</sup> for >6-30 GHz,  
390 and 1 cm<sup>2</sup> above 30 GHz) because this is sufficiently similar to the ideal averaging area across  
391 frequency. Further, as 6 minutes is an appropriate averaging interval (Morimoto et al., 2017)  
392 and as approximately 200 W m<sup>-2</sup> is required to produce the Type-1 tissue operational adverse  
393 health effect threshold of a 5 °C local temperature rise (Sasaki et al., 2017), ICNIRP has set the  
394 transmitted power density value for local heating, averaged over 6 minutes and either 4 cm<sup>2</sup>  
395 (>6-30 GHz) or 1 cm<sup>2</sup> (>30 GHz), at 200 W m<sup>-2</sup>.

#### 396 4.3.3.2. RAPID TEMPERATURE RISE

397 For some types of exposure, rapid temperature elevation can result in ‘hot spots’,  
398 heterogeneous temperature distribution over tissue mass (Foster et al 2016; Morimoto et al  
399 2017; Laakso et al., 2017). This suggests the need to consider averaging over smaller time-  
400 intervals for certain types of exposure. Hot spots can occur for short duration exposures  
401 because there is not sufficient time for heat to dissipate (or average out) over tissue. This effect  
402 is more pronounced as frequency increases, due to the smaller penetration depth.

403 To account for such heterogeneous temperature distributions, an adjustment to the steady-state  
404 exposure level is required. This can be achieved by specifying the maximum exposure level  
405 allowed, as a function of time, in order to restrict temperature elevation to below the  
406 operational adverse health effect thresholds. Note that for this specification, exposure from any  
407 pulse, group of pulses, or subgroup of pulses in a train, delivered in  $t$  seconds, must not exceed  
408 the below formulae (in order to ensure that the temperature thresholds are not exceeded). From  
409 400 MHz to 6 GHz, ICNIRP specifies the limit in terms of specific absorption (SA) of any 10 g  
410 cubic mass, where SA is restricted to  $500+354(t-1)^{0.5}$  J kg<sup>-1</sup> for both Head and Torso, and Limb  
411 exposure, where  $t$  is exposure interval (in seconds); for intervals less than 1 second, SA is set at  
412 500 J kg<sup>-1</sup>. No distinction is made between Head and Torso, and Limb exposure for this  
413 operational adverse health effect threshold, because recent modelling shows that the  
414 operational health effect thresholds for both tissue types will be met simultaneously. There is  
415 no brief-interval exposure level specified below 400 MHz because, due to the large thermal  
416 diffusion length below 400 MHz, the total SA resulting from the 6 minute local SAR average  
417 (corresponding to the operational adverse health effect threshold) cannot increase temperature  
418 by more than the operational adverse health effect threshold (regardless of the particular  
419 pattern of pulses or brief exposures). Above 6 GHz, ICNIRP specifies the limit in terms of  
420 transmitted energy density ( $H_{tr}$ ) over any 4 cm<sup>2</sup> or 1 cm<sup>2</sup> area (for >6-30 GHz, and >30 GHz  
421 respectively), where  $H_{tr}$  is specified as  $5+3.54(t-1)^{0.5}$  kJ m<sup>-2</sup> for intervals between 1 and 360  
422 seconds, where ‘ $t$ ’ is interval in seconds (Foster et al., 2016); for intervals less than a second,  
423 the value is set at 5 kJ m<sup>-2</sup>. The SA and  $H_{tr}$  values are conservative in that, under worst-case  
424 (adiabatic) conditions, they are not sufficient to raise temperature by 5 °C.

### 425 5. GUIDELINES FOR LIMITING RADIOFREQUENCY EMF EXPOSURE

426 As described in Section 4, radiofrequency EMF thresholds for a number of operational adverse  
427 health effects were identified (increased body core or local tissue temperature due to absorption  
428 of EMF power). Exposure limits have been derived from these and are described below.

429 To be compliant with the present guidelines, exposure cannot exceed any of the restrictions  
430 described below, nor those for the 100 kHz – 10 MHz range of the ICNIRP (2010) low  
431 frequency guidelines, which includes protection against nerve stimulation. The present  
432 guidelines restrict radiofrequency EMF to levels that *do not cause any known health effect*,

433 using relationships between exposure and tissue heating, as well as exposure and health more  
434 generally, to do so. Although the guidelines protect against significant temperature rise due to  
435 EMF power deposition within tissue, they do not limit other sources of heat (i.e. that are not  
436 due to radiofrequency EMF). For information concerning the relation between workers' health  
437 and *total* thermal load, see ACGIH 2017.

## 438 **5.1. BASIC RESTRICTIONS**

439 Basic restriction values are provided in Table 2-3, with an overview of their derivation  
440 described below. A more detailed description of issues pertinent to the basic restrictions is  
441 provided in Appendix A. Note that for the basic restrictions described below, a pregnant  
442 woman is treated as a member of the general public. This is because recent modelling suggests  
443 that for both whole body and local exposure scenarios, exposure of the mother at the  
444 occupational basic restrictions can lead to fetal exposures that exceed the general public basic  
445 restrictions.

### 446 **5.1.1. WHOLE BODY AVERAGE SAR (100 kHz – 300 GHz)**

447 As described in Section 4.3.3.1.1, the guidelines take a whole body average SAR of  $4 \text{ W kg}^{-1}$ ,  
448 averaged over the entire body mass and a 30-minute interval, as the exposure level  
449 corresponding to the operational adverse threshold of an increase in body core temperature of  $1$   
450  $^{\circ}\text{C}$ . A reduction factor of 10 was applied to this threshold for occupational exposure to account  
451 for scientific uncertainty, as well as differences in thermal baselines, thermoregulation ability  
452 and body core temperature health threshold across the population. Variability in an individual's  
453 ability to regulate their body core temperature is particularly important as it is dependent on a  
454 range of factors that the guidelines cannot control, such as central and peripherally-mediated  
455 modification to blood perfusion and sweat rate (which are in turn affected by a range of other  
456 factors, including age and certain medical conditions), as well as behavior and environmental  
457 conditions.

458 The reduction factor of 10 makes the basic restriction for occupational exposure a whole body  
459 average SAR of  $0.4 \text{ W kg}^{-1}$ , averaged over 30 minutes. Although this means that SAR can be  
460 larger for smaller time intervals, this will not affect body core temperature rise appreciably  
461 because the temperature will be 'averaged-out' within the body over the 30 minute interval,  
462 and it is this time-averaged temperature elevation that is relevant to body core temperature-  
463 related health effects. Further, as both whole body and local restrictions must be met  
464 simultaneously, exposures sufficiently high to be hazardous locally will be protected against by  
465 the local limits described below.

466 As the general public cannot be expected to be aware of exposures and thus to mitigate risk, a  
467 reduction factor of 50 was applied for the general public, reducing the general public restriction  
468 to  $0.08 \text{ W kg}^{-1}$ . It is noteworthy that the scientific uncertainty pertaining to both dosimetry and  
469 potential health consequences of whole body radiofrequency exposure have reduced  
470 substantially since the ICNIRP 1998 Guidelines. This would justify less conservative reduction  
471 factors, but as ICNIRP considers that the benefits of maintaining stable basic restrictions  
472 outweighs any benefits that subtle changes to the basic restrictions would provide, ICNIRP has  
473 retained the conservative reduction factors and the ICNIRP 1998 whole body average basic  
474 restrictions. Similarly, although temperature rise is more superficial as frequency increases  
475 (and thus it is easier for the heat to be lost to the environment), the whole body average SAR  
476 limits above 6 GHz have been conservatively set the same as those below 6 GHz.

477 **5.1.2 Local SAR (100 kHz – 6 GHz)**

478 **Head and torso**

479 As described in Section 4.3.3.1.2, the guidelines take a SAR of  $20 \text{ W kg}^{-1}$ , averaged over a 10  
480 g cubic mass and 6 minute interval, within the 100 kHz to 6 GHz range, as the local exposure  
481 corresponding to the operational adverse health effect threshold for the Head and Torso ( $5 \text{ }^\circ\text{C}$   
482 in Type-1 tissue and  $2 \text{ }^\circ\text{C}$  in Type-2 tissue). A reduction factor of 2 was applied to this  
483 threshold for occupational exposure to account for scientific uncertainty, as well as differences  
484 in both thermal baselines and thermoregulation ability across the population. Reduction factors  
485 for local exposure are smaller than for whole body exposure because the associated health  
486 effect threshold is less dependent on the highly variable centrally-mediated thermoregulatory  
487 processes, and because the associated health effect is less serious medically.

488 The reduction factor of 2 makes the basic restriction for occupational exposure a  $\text{SAR}_{10\text{g}}$  of  $10$   
489  $\text{W kg}^{-1}$ , averaged over a 6 minute interval. As the general public cannot be expected to be  
490 aware of exposures and thus to mitigate risk, a reduction factor of 10 was applied for the  
491 general public, reducing the general public restriction to  $2 \text{ W kg}^{-1}$ .

492 **Limbs**

493 As described in Section 4.3.3.1.2, the guidelines take a SAR of  $40 \text{ W kg}^{-1}$ , averaged over a 10  
494 g cubic mass and 6 minute interval, within the 100 kHz to 6 GHz range, as the local exposure  
495 corresponding to the operational adverse health effect threshold for the limbs of  $5 \text{ }^\circ\text{C}$  local  
496 temperature elevation. As per the Head and Torso restrictions, a reduction factor of 2 was  
497 applied to this threshold for occupational exposure to account for scientific uncertainty, as well  
498 as differences in both thermal baselines and thermoregulation ability across the population,  
499 resulting in a basic restriction for occupational exposure a  $\text{SAR}_{10\text{g}}$  of  $20 \text{ W kg}^{-1}$ . As the general  
500 public cannot be expected to be aware of exposures and thus to mitigate risk, a reduction factor  
501 of 10 was applied for the general public, reducing the general public restriction to  $4 \text{ W kg}^{-1}$ .

502 **5.1.3. LOCAL SA (400 MHz – 6 GHz)**

503 As described in 4.3.3.2, an additional constraint is required within this frequency range to  
504 ensure that the cumulative energy permitted by the 6 minute average  $\text{SAR}_{10\text{g}}$  basic restriction  
505 is not absorbed by tissue too rapidly. Accordingly, for both the Head and Torso, and Limbs,  
506 ICNIRP set an SA level for exposure intervals of less than 6 minutes, as a function of time, to  
507 limit temperature elevation to below the operational adverse health effect thresholds. This SA  
508 level, averaged over a 10 g cubic mass, is given by  $500+354(t-1)^{0.5} \text{ J kg}^{-1}$  for exposure  
509 durations of at least 1 second, where 't' is exposure duration in seconds for a single pulse, and  
510  $500 \text{ J kg}^{-1}$  for exposure durations less than 1 second. The exposure from any group of pulses, or  
511 subgroup of pulses in a train, delivered in t seconds should not exceed this threshold. This  
512 threshold is for both the Head and Torso, and Limbs, because in both cases energy absorption  
513 is larger in superficial tissues, with the result being that operational adverse health effect  
514 thresholds will not be exceeded for either Type-1 or Type-2 tissue.

515 As per the  $\text{SAR}_{10\text{g}}$  basic restrictions, a reduction factor of 2 was applied to this threshold for  
516 occupational exposure to account for scientific uncertainty, as well as differences in both  
517 thermal baselines and thermoregulation ability across the population, resulting in a basic  
518 restriction for occupational exposure of  $250+177(t-1)^{0.5} \text{ J kg}^{-1}$ . As the general public cannot be  
519 expected to be aware of exposures and thus to mitigate risk, a reduction factor of 10 was  
520 applied for the general public, reducing the general public restriction to  $50+35.4(t-1)^{0.5} \text{ J kg}^{-1}$ .



#### 521 **5.1.4. LOCAL TRANSMITTED POWER DENSITY (>6 GHz – 300 GHz)**

522 As described in Section 4.3.3.1.2, the guidelines take a transmitted power density of  $200 \text{ W m}^{-2}$ ,  
523 averaged over 6 minutes and either  $4 \text{ cm}^2$  (>6 to 30 GHz) or  $1 \text{ cm}^2$  (>30 to 300 GHz) surface  
524 area of the body, within the >6 to 300 GHz range, as the local exposure corresponding to the  
525 operational adverse health effect threshold for both the Head and Torso, and Limb regions (5  
526 and  $2 \text{ }^\circ\text{C}$  local temperature elevation in Type-1 and Type-2 tissue respectively). As per the  
527 local SAR restrictions, a reduction factor of 2 was applied to this threshold for occupational  
528 exposure to account for scientific uncertainty, as well as differences in both thermal baselines  
529 and thermoregulation ability across the population. This results in a basic restriction for  
530 occupational exposure of  $100 \text{ W m}^{-2}$ . As the general public cannot be expected to be aware of  
531 these exposures and thus to mitigate risk, a reduction factor of 10 was applied, which reduces  
532 the general public basic restriction to  $20 \text{ W m}^{-2}$ .

#### 533 **5.1.5. LOCAL TRANSMITTED ENERGY DENSITY (>6 GHz – 300 GHz)**

534 As described in 4.3.3.2, an additional constraint is required within this frequency range to  
535 ensure that the cumulative energy permitted by the 6 minute average transmitted power density  
536 basic restriction is not absorbed by tissue too rapidly. Accordingly, for both the Head and  
537 Torso, and Limbs, ICNIRP set a transmitted energy density level for exposure intervals of less  
538 than 6 minutes, as a function of time, to limit temperature elevation to below the operational  
539 adverse health effect thresholds for both Type-1 and Type-2 tissue. This transmitted energy  
540 density level, averaged over  $4 \text{ cm}^2$  (from >6 to 30 GHz) or  $1 \text{ cm}^2$  (from >30 to 300 GHz), is  
541 given by  $5+3.54(t-1)^{0.5} \text{ kJ m}^{-2}$  for exposure durations of at least 1 second, where 't' is exposure  
542 duration in seconds, and  $5 \text{ kJ m}^{-2}$  for exposure durations less than 1 second. The exposure from  
543 any group of pulses, or subgroup of pulses in a train, delivered in t seconds, should not exceed  
544 this threshold.

545 As per the transmitted power density basic restrictions, a reduction factor of 2 was applied to  
546 this threshold for occupational exposure to account for scientific uncertainty, as well as  
547 differences in both thermal baselines and thermoregulation ability across the population,  
548 resulting in a basic restriction for occupational exposure of  $2.5+1.77(t-1)^{0.5} \text{ kJ m}^{-2}$  for exposure  
549 durations of at least 1 second, and  $2.5 \text{ kJ m}^{-2}$  for exposure durations less than 1 second. As the  
550 general public cannot be expected to be aware of exposures and thus to mitigate risk, a  
551 reduction factor of 10 was applied for the general public, reducing the general public restriction  
552 to  $0.5+0.354(t-1)^{0.5} \text{ kJ m}^{-2}$  for exposure durations of at least 1 second, and  $0.5 \text{ kJ m}^{-2}$  for  
553 exposure durations less than 1 second.

#### 554 **5.1.6. RISK MITIGATION CONSIDERATIONS FOR OCCUPATIONAL EXPOSURE**

555 The relevant health effects that the whole body SAR restrictions protect against are increased  
556 cardiovascular load (due to the work that the cardiovascular system must perform in order to  
557 restrict body core temperature rise), and where temperature rise is not restricted to a safe level,  
558 a cascade of functional changes that may lead to both reversible and irreversible damage to  
559 tissue (including brain, heart and kidney). These effects typically require body core  
560 temperatures of greater than  $40 \text{ }^\circ\text{C}$  (or an increase of approximately  $3 \text{ }^\circ\text{C}$  relative to  
561 normothermia). Large reduction factors have thus been used to make it extremely unlikely that  
562 radiofrequency-induced temperature rise would exceed  $1 \text{ }^\circ\text{C}$  (occupational limits have been set  
563 that would, under normothermic conditions, lead to body core temperature rises of  $< 0.1 \text{ }^\circ\text{C}$ ),  
564 but care must be exercised when a worker is subject to other heat sources that may add to that  
565 of the radiofrequency exposure, such as high environmental temperatures, high work rates, or  
566 impediments to normal thermoregulation (such as thermally insulating clothing or certain  
567 medical conditions). Where significant heat is expected from other sources, it is advised that

568 workers have a suitable means of verifying their body core temperature (see ACGIH 2018b for  
569 further guidance).

570 The relevant health effects that the local basic restrictions protect against are pain and  
571 thermally-induced tissue damage. Within superficial (Type-1) tissue, pain (due to stimulation  
572 of nociceptors) and tissue damage (due to denaturation of tissue) typically require temperatures  
573 above approximately 41 °C. Occupational exposure of the limbs is unlikely to increase local  
574 temperature by more than 2.5 °C, and given that superficial temperatures are normally below  
575 31-36 °C, it is unlikely that radiofrequency exposure of superficial tissue, in itself, would result  
576 in either pain or tissue damage. Within Type-2 tissue of the Head and Torso (which excludes  
577 superficial tissue), harm is also unlikely to occur at temperatures below 41 °C. As occupational  
578 exposure of the Head and Torso tissue is unlikely to increase temperature by more than 1 °C,  
579 and given that body core temperature is normally around 37 °C, it is unlikely that  
580 radiofrequency EMF exposure would lead to temperature elevations sufficient to harm Type-2  
581 tissue or tissue function.

582 However, care must be exercised when a worker is subject to other heat sources that may add  
583 to that of the radiofrequency exposure, such as high environmental temperatures, high work  
584 rates, or impediments to normal thermoregulation (such as thermally insulating clothing or  
585 certain medical conditions). For superficial exposure scenarios, local thermal discomfort or  
586 pain are important indicators of potential thermal tissue damage. It is thus important,  
587 particularly in situations where other thermal stressors are present, that the worker understands  
588 about the effect that radiofrequency exposure can contribute to their thermal load.

589  
590 **Table 2.** Basic restrictions for electric, magnetic and electromagnetic field exposure ( $\geq 6$   
591 minutes).<sup>a</sup>

Exposure Scenario	Frequency Range	Whole body average SAR ( $\text{W kg}^{-1}$ )	Local head/torso SAR ( $\text{W kg}^{-1}$ )	Local limb SAR ( $\text{W kg}^{-1}$ )	Local $S_{tr}$ ( $\text{W m}^{-2}$ )
Occupational	100 kHz – 6 GHz	0.4	10	20	---
	>6 GHz – 300 GHz	0.4	---	---	100
General Public	100 kHz – 6 GHz	0.08	2	4	---
	>6 GHz – 300 GHz	0.08	---	---	20

- 592 <sup>a</sup> Note:
- 593 1. Whole body average SAR is to be averaged over 30 minutes.
- 594 2. Local SAR and  $S_{tr}$  exposures are to be averaged over 6 minutes.
- 595 3. Local SAR is to be averaged over a 10 g cubic mass.
- 596 4. Local  $S_{tr}$  is to be averaged over a 4 cm<sup>2</sup> (>6-30 GHz) or 1 cm<sup>2</sup> (>30 GHz) square.
- 597 5. Where relevant, equivalent incident plane wave power density can be used in place of  
598 incident plane wave power density.
- 599 6. “---” indicates that this cell is not relevant to the basic restrictions.
- 600

601 **Table 3.** Basic restrictions for electric, magnetic and electromagnetic field exposure (< 6  
602 minutes).<sup>a</sup>

Exposure Scenario	Frequency Range	Local SA ( $\text{J kg}^{-1}$ )	Local $H_{tr}$ ( $\text{kJ m}^{-2}$ )
-------------------	-----------------	---------------------------------	---------------------------------------



Occupational	400 MHz – 6 GHz	$250+177(t-1)^{0.5}$	---
	>6 GHz – 300 GHz	---	$2.5+1.770(t-1)^{0.5}$
General Public	400 MHz – 6 GHz	$50+35.4(t-1)^{0.5}$	---
	>6 GHz – 300 GHz	---	$0.5+0.354(t-1)^{0.5}$

<sup>a</sup> Note:

1. SA is to be averaged over a 10-g cubic mass.
2.  $H_{tr}$  is to be averaged over a  $4\text{ cm}^2$  (>6-30 GHz) or  $1\text{ cm}^2$  (>30 GHz) square.
3. ‘t’ is time interval, in seconds; for  $t < 1$ , ‘t = 1’ must be used.
4. Limits must be met for all values of  $t < 360$  seconds, regardless of the temporal characteristics of the brief exposure itself.
5. “---” indicates that this cell is not relevant to the basic restrictions.

## 5.2. REFERENCE LEVELS

Reference levels have been derived from a combination of computation and measurement studies to provide a means of demonstrating compliance using quantities that are more-easily assessed than basic restrictions, but that provide an equivalent level of protection to the basic restrictions for worst-case exposure scenarios. However, as the derivations rely on conservative assumptions, in most exposure scenarios the reference levels will be more conservative than the corresponding basic restrictions. For the purpose of these guidelines, compliance is demonstrated if either the relevant reference levels or basic restrictions are complied with; both are not required. Further detail regarding the reference levels is provided in Appendix A.

Separate **E**-field, **H**-field and incident power density far-field reference levels (depending on frequency) have been set for occupational and general public exposure separately, to protect against effects associated with whole body exposure (averaged over 30 minutes; Table 4), local exposure (averaged over 6 minutes; Table 5), and brief local exposure (averaged over less than 6 minutes; Table 6). Although these reference levels will be more conservative than the corresponding basic restrictions in most exposure scenarios, effects of grounding near human body resonance frequencies can potentially increase exposures beyond the basic restrictions. An additional (limb current) reference level has been set to account for this (averaged over 6 minutes; Table 7). Reference level values are provided in Tables 4-7, with application details given as ‘notes’ in the corresponding table legends; ‘numbered’ notes represent detail pertinent to exposure in the far-field, whereas notes prefixed with ‘symbols’ represent detail pertinent to near-field exposure.

Below 30 MHz, compliance with the present guidelines will typically be evaluated in the zone of the reactive and radiative near-field. In such cases it is rare for there to be a plane wave incident to a human body. The whole body average **E**-field and **H**-field reference levels within this range (Table 4) have therefore been derived separately from calculations assuming whole body exposure to capacitive near-field (only **E**-field) or inductive near-field (only **H**-field). Above 30 MHz it is difficult to set reference levels for exposure within the reactive and radiative near-field due to a range of factors. Where suitable dosimetry was not available to set reference levels in the near-field, ICNIRP applied additional constraints to the far-field reference levels to provide conservative reference levels that can be used for near-field exposure. However, this was not possible for some exposure scenarios; in such cases, compliance with the basic restrictions is required. Reference level values above 30 MHz in Tables 4-6 refer to far-field exposure conditions, with any accommodation for near-field exposures specified in the notes provided in the tables. As a rough guide,  $< \lambda/2\pi$  m, between  $\lambda/2\pi$  and  $2D^2/\lambda$  m, and  $> 2D^2/\lambda$  m from the antenna correspond approximately to the reactive

645 near-field, radiative near-field and far-field respectively, where  $D$  and  $\lambda$  refer to antenna  
 646 diameter and wavelength respectively, in meters. However, due to a range of factors that  
 647 impact on the degree to which these definitions are appropriate for application to the reference  
 648 levels, input from the compliance community is required to determine which of these field  
 649 types is most appropriate for a given exposure.

650 ICNIRP is aware that for some exposure scenarios, EMFs at the reference levels described  
 651 below could potentially result in exposure that exceeds basic restrictions. Where such scenarios  
 652 were identified, ICNIRP determined whether the reference levels needed to be reduced by  
 653 considering the magnitude of the difference between the resultant tissue exposure and basic  
 654 restriction (including comparison with the associated dosimetric uncertainty), and whether the  
 655 violation was likely to affect health (including consideration of the degree of conservativeness  
 656 in the associated basic restriction). Where the difference was small, and where it would not  
 657 impact on health, reference levels were set that can potentially result in exposures that exceed  
 658 the basic restrictions. This reduces unnecessary changes and maintains the stability of the  
 659 guidelines (relative to ICNIRP 1998), which ICNIRP views as beneficial to the whole  
 660 community.

661 This situation has been shown to occur in terms of the reference levels corresponding to whole  
 662 body average SAR basic restrictions, which, in the frequency range of body resonance (up to  
 663 100 MHz) and from 1 to 4 GHz, can potentially lead to whole body average SARs that exceed  
 664 the basic restrictions. The exposure scenario where this can potentially occur is very specific,  
 665 requiring a small stature person (such as a 3-year old child) to be extended (e.g. standing) for at  
 666 least 30 minutes, while being subject to a plane wave exposure within the above frequency  
 667 ranges, incident to the child from the front to back. The resultant SAR elevation is small  
 668 relative to the basic restriction (circa 40%, which is similar to the *in vivo* whole body average  
 669 SAR measurement uncertainty; Flintoft et al., 2014), there are many levels of conservativeness  
 670 built into the basic restriction derivation itself, and importantly, this will not impact on health.  
 671 This latter point is important because the basic restriction that this relates to was set to protect  
 672 against body core temperature elevations of greater than 1 °C, and being of small stature, the  
 673 individual in this hypothetical exposure scenario would more-easily dissipate heat to the  
 674 environment than a larger person due to their increased body ‘surface area to mass ratio’  
 675 ((Hirata et al., 2013). Within a small stature person the net effect of this ‘increased whole body  
 676 SAR’ and ‘increased heat loss’ would be a smaller temperature rise than would occur in a  
 677 person of larger stature. ICNIRP has thus not altered the reference levels to account for this  
 678 situation, because to do so would reduce the continuity of its guidelines (with those of ICNIRP  
 679 1998) without any benefit to health and safety.  
 680

681 **Table 4.** Reference levels for whole body exposure to time-varying far-field electric, magnetic  
 682 and electromagnetic fields, from 100 kHz to 300 GHz (unperturbed rms values).<sup>a</sup>

Exposure Scenario	Frequency Range	E-field strength (V m <sup>-1</sup> )	H-field strength (A m <sup>-1</sup> )	Incident plane wave power density ( $S_{inc}$ ) (W m <sup>-2</sup> )
Occupational	0.1-20 MHz <sup>#</sup>	1220/f	4.9/f	----
	>20-30 MHz <sup>#</sup>	61	4.9/f	----
	>30-400 MHz <sup>#</sup>	61	0.16	10
	>400-2,000 MHz <sup>*</sup>	3f <sup>0.5</sup>	0.008f <sup>0.5</sup>	f/40
	>2-300 GHz <sup>*</sup>	----	----	50

	0.1-20 MHz <sup>#</sup>	560/f	2.2/f	----
General	>20-30 MHz <sup>#</sup>	28	2.2/f	----
Public	>30-400 MHz <sup>#</sup>	28	0.073	2
	>400-2,000 MHz <sup>*</sup>	1.375f <sup>0.5</sup>	0.0037f <sup>0.5</sup>	f/200
	>2-300 GHz <sup>*</sup>	----	----	10

- 683 <sup>a</sup> Note:
- 684 1.  $f$  is frequency in MHz.
- 685 2.  $S_{inc}$ ,  $E^2$  and  $H^2$  are to be averaged over 30 minutes, over the whole body space. **E**- and **H**-
- 686 field values are to be derived from these averaged values.
- 687 3. For frequencies up to 2 GHz, compliance is demonstrated if either the **E**-field, **H**-field or  $S_{inc}$
- 688 value is within the reference levels; only one is required.
- 689 4. “----” indicates that this cell is not relevant to the reference levels.
- 690 #. For frequencies up to 400 MHz: For reactive and radiative near-field exposure conditions,
- 691 exposure is compliant with the reference levels if both **E**- and **H**-field levels are within the
- 692 relevant far-field reference levels.
- 693 \*. For frequencies above 400 MHz: Far-field reference levels are also applicable to radiative
- 694 near-field exposure conditions; no reference level is provided for reactive near-field exposure
- 695 conditions.

696

697 **Table 5.** Reference levels for local exposure to time varying far-field electric, magnetic and

698 electromagnetic fields, from 100 kHz to 300 GHz, for time intervals  $\geq 6$  minutes (unperturbed

699 rms values).<sup>a</sup>

Exposure Scenario	Frequency Range	Incident plane wave power density ( $S_{inc}$ ) ( $W m^{-2}$ )
Occupational	100 kHz – 400 MHz <sup>#</sup>	See note 2
	>400 MHz – 6 GHz <sup>#</sup>	See note 3
	>6 – 300 GHz <sup>*</sup>	275f <sup>0.177</sup>
	300 GHz <sup>*</sup>	100
General Public	100 kHz – 400 MHz <sup>#</sup>	See note 2
	>400 MHz – 6 GHz <sup>#</sup>	See note 3
	>6 – 300 GHz <sup>*</sup>	55f <sup>0.177</sup>
	300 GHz <sup>*</sup>	20

- 701 <sup>a</sup> Note:
- 702 1.  $f$  is frequency in GHz.
- 703 2. For frequencies up to 400 MHz, exposure is compliant with the reference levels if the spatial
- 704 peak value, averaged over 6 minutes, is less than the corresponding whole body average far-
- 705 field reference levels (from Table 4). Where relevant, equivalent incident plane wave power
- 706 density can be used in place of incident plane wave power density.
- 707 3. For frequencies >400 MHz to 6 GHz, Table 6 reference levels averaged over 6 minutes are
- 708 to be used (i.e.  $t = 360$  seconds).
- 709 4.  $S_{inc}$  is to be averaged over 6-minutes, over a 4-cm<sup>2</sup> (66-30 GHz) or 1-cm<sup>2</sup> (>30-300 GHz)
- 710 square region in space, approximating the body surface.
- 711 5. “----” indicates that this cell is not relevant to the reference levels.

712 #. For frequencies up to 6 GHz, far-field reference levels are also applicable to radiative and  
 713 reactive near-field exposure conditions.

714 \*. For frequencies above 6 GHz, far-field reference levels are also applicable to radiative near-  
 715 field exposure conditions; no reference levels are provided for reactive near-field exposure  
 716 conditions within this frequency range.

717  
 718 **Table 6.** Reference levels for local exposure to time varying far-field electric, magnetic and  
 719 electromagnetic fields, from 100 kHz to 300 GHz, for time intervals  $\leq 6$  minutes (unperturbed  
 720 rms values).<sup>a</sup>

Exposure Scenario	Frequency Range	Incident plane wave energy density ( $H_{inc}$ ) (kJ m <sup>-2</sup> )
Occupational	100 kHz – 400 MHz	See note 2
	>400 MHz – 6 GHz <sup>#</sup>	$0.8f^{0.51}[2.5+1.77(t-1)^{0.5}]$
	>6 – 300 GHz <sup>*</sup>	$2.75f^{0.177}2.5+1.77(t-1)^{0.5}]$
General Public	100 kHz – 400 MHz	See note 2
	>400 MHz – 6 GHz <sup>#</sup>	$0.8f^{0.51}[0.5+0.354(t-1)^{0.5}]$
	>6 – 300 GHz <sup>*</sup>	$2.75f^{0.177}[0.5+0.354(t-1)^{0.5}]$

721 <sup>a</sup> Note:

722 1.  $f$  is frequency in GHz;  $t$  is time interval in seconds.

723 2. For frequencies 100 kHz – 400 MHz, no additional constraint is imposed for brief intervals  
 724 (the 6 minute average reference levels described in Table 5 are to be used). Where relevant,  
 725 equivalent incident plane wave energy density can be used in place of incident plane wave  
 726 energy density.

727 3. Peak spatial  $H_{inc}$  is to be used for frequencies >400 MHz – 6 GHz;  $H_{inc}$  is to be averaged  
 728 over a 4 cm<sup>2</sup> (6 – 30 GHz) or 1 cm<sup>2</sup> (>30 – 300 GHz) square region in space, representative of  
 729 body surface.

730 4. The exposure from any group of pulses, or subgroup of pulses in a train, delivered in  $t$   
 731 seconds, should not exceed the limits in this table.

732 #. For frequencies 400 MHz to 6 GHz, for reactive and radiative near-field exposure conditions,  
 733 exposure is compliant with the reference levels if both the spatial peaks of the equivalent  
 734 incident plane wave energy density, based on  $E$ - and  $H$ -field, are less than the corresponding  
 735  $H_{inc}$  reference level.

736 \*. For frequencies above 6 GHz, far-field reference levels are also applicable to radiative near-  
 737 field exposure conditions; no reference level is provided for reactive near-field exposure  
 738 conditions within this frequency range.

739  
 740 **Table 7.** Reference levels for current induced in any limb at frequencies between 100 kHz and  
 741 110 MHz. <sup>a</sup>

Exposure Scenario	Frequency Range	Current $I_L$ (mA)
Occupational	100 kHz – 110 MHz	100
General Public	100 kHz – 110 MHz	45

742 <sup>a</sup>Note

743 1.  $I_L^2$  values are averaged over 6 minutes. Current values are to be derived from these averaged  
 744 values.

745 2. Limb current reference levels are not provided for any other frequency range.

### 746 5.3. GUIDANCE

#### 747 5.3.1. CONTACT CURRENTS

748 Within approximately the 100 kHz - 110 MHz range, contact currents can occur when a person  
749 touches a conducting object that is within an electric or magnetic field, causing current flow  
750 between object and person. At high levels these can result in nerve stimulation or pain (and  
751 potentially tissue damage), depending on EMF frequency (Kavet et al. 2014, Tell and Tell  
752 2018). This can be a particular concern around large radiofrequency transmitters, such as are  
753 found near high power antennas used for broadcasting below 30 MHz, where there have been  
754 sporadic reports of pain and burn-related accidents. Contact currents occur at the region of  
755 contact, with smaller contact regions producing larger biological effects (given the same  
756 current). This is due to the larger current density ( $A m^{-2}$ ), and consequently the higher localized  
757 SAR and E-field in the body.

758 Exposure due to contact currents is indirect, in that it requires an intermediate conducting  
759 object to conduct the field. This makes contact current exposure unpredictable, due to both  
760 behavioral (e.g. grasping versus finger contact) and environmental (e.g. configuration of  
761 conductive objects) conditions, and reduces ICNIRP's ability to protect against them. Of  
762 particular importance is the heterogeneity of the current density passing to and being absorbed  
763 by the person, which is due not only to the contact area, but also to the tissue conductivity,  
764 density and heat capacity of the tissue through which the current passes, and most importantly  
765 the resistance between conducting object and contacting tissue (Tell and Tell 2018).

766 Accordingly, these guidelines do not provide strict limits for contact currents, and instead  
767 provide 'guidance' to assist those responsible for transmitting high-power radiofrequency  
768 fields to understand contact currents, the potential hazards, and how to mitigate such hazards.  
769 For the purpose of specification, ICNIRP here defines high-power radiofrequency fields as  
770 those emitting greater than  $100 V m^{-1}$  at their source.

771 There is limited research available on the relation between contact currents and health. In terms  
772 of pain, the health effect arising from the lowest contact current level, the main data comes  
773 from Chatterjee et al. (1986). In that study sensation and pain were assessed in a large adult  
774 cohort as a function of contact current frequency and contact type (point versus grasp contact).  
775 Reversible, painful heat sensations were found to occur with average (point) contact current  
776 thresholds of 46 mA within the 100 kHz to 10 MHz range tested, and these required at least 10  
777 seconds of exposure to occur. Thresholds were frequency-independent within that range, and  
778 thresholds for grasping contact were substantially higher than those for point contact.

779 However, given that the threshold value was an average across the participants, and given the  
780 standard deviation of the thresholds reported, ICNIRP considers that the lowest threshold  
781 across the cohort would have been approximately 20 mA. Further, modelling from that data  
782 suggests that children would have lower thresholds; extrapolating from Chatterjee et al. (1986)  
783 and Chan et al. (2015), we would expect the lowest threshold in children to be within the range  
784 of 10 mA. The upper frequency of contact current capable of causing harm is also not known.  
785 Although the ICNIRP 1998 guidelines specified that contact currents should be protected  
786 against from 100 kHz to 110 MHz, Chatterjee et al. (1986) only tested up to 10 MHz, and Tell  
787 and Tell (2018) reported strong reductions in contact current magnitude from about 1 MHz to  
788 28 MHz (and did not assess higher frequencies). Thus it is not clear that contact currents will  
789 remain a health hazard across the entire 100 kHz to 110 MHz range.

790 In determining the likelihood and nature of hazard due to potential contact current scenarios,  
791 ICNIRP views the following as important for the responsible person in managing risk  
792 associated with contact currents within the 100 kHz to 110 MHz EMF region. This may also be  
793 useful for assisting the responsible person in conducting a risk-benefit analysis associated with  
794 allowing a person into a radiofrequency EMF environment that may result in contact currents.

- 795 • Available data suggest that contact current thresholds for reversible, mild pain, for adults  
796 and children, are likely to be approximately 20 mA and 10 mA respectively;
- 797 • Contact current thresholds for tissue damage, which can be irreversible, have not been  
798 determined, making it difficult to differentiate between contact current levels capable of  
799 causing pain versus tissue damage;
- 800 • There is currently no evidence that hazards associated with contact currents occur for  
801 radiofrequency radiation above about 30 MHz, but it may be a useful conservative  
802 approach to assume that they can occur up to 110 MHz;
- 803 • Contact current magnitude will increase as a function of field strength and is affected by  
804 conducting-object configuration;
- 805 • Risk of contact current hazards can be minimized by training workers to avoid contact with  
806 conducting objects, but where contact is required
  - 807 ○ Large metallic objects should be connected to ground (grounding)
  - 808 ○ Workers should make contact via insulating materials (e.g. radiofrequency  
809 protective gloves).
  - 810 ○ Workers should be made aware of the risks, including the possibility of ‘surprise’,  
811 which may impact on safety in ways other than the direct impact of the current on  
812 tissue (for example, by causing accidents).

#### 813 **5.4. SIMULTANEOUS EXPOSURE TO MULTIPLE FREQUENCY FIELDS**

814 It is important to determine whether, in situations of simultaneous exposure to fields of  
815 different frequencies, these exposures are additive in their effects. Additivity should be  
816 examined separately for the effects of thermal and electrical stimulation, and restrictions met  
817 after accounting for such additivity. The formulae below apply to relevant frequencies under  
818 practical exposure situations. The below reference level summation formulae assume worst-  
819 case conditions among the fields from multiple sources. As a result, typical exposure situations  
820 may in practice require less restrictive exposure levels than indicated by the formulae for the  
821 reference levels (but would require compliance to be demonstrated with basic restrictions to  
822 demonstrate this).

##### 823 **5.4.1 Basic restrictions $\geq 6$ minutes**

824 Above 100 kHz, whole body averaged SAR should be added according to;

825

$$\sum_{i=100 \text{ kHz}}^{300 \text{ GHz}} \frac{SAR_i}{SAR_L} \leq 1 \quad (\text{Eqn. 1}),$$

826

827 and local SAR and transmitted power density values added according to;

828



$$\sum_{i=100 \text{ kHz}}^{6 \text{ GHz}} \frac{SAR_i}{SAR_L} + \sum_{i>6 \text{ GHz}}^{300 \text{ GHz}} \frac{S_{tr,i}}{S_{tr,L}} \leq 1, \quad (\text{Eqn. 2}),$$

829  
 830 where,  $SAR_i$  is the SAR caused by exposure at frequency  $i$ ;  $SAR_L$  is the SAR limit given in  
 831 Table 2;  $S_{tr,i}$  is the transmitted power density at frequency  $i$ , and  $S_{tr,L}$  is the transmitted power  
 832 density limit given in Table 2.

#### 833 5.4.2 Reference levels $\geq 6$ minutes

834 For practical application of the basic restrictions, the following criteria regarding reference  
 835 levels of field strengths should be applied to the field levels;

$$\sum_{i=100 \text{ kHz}}^{2 \text{ GHz}} \left( \frac{E_i}{E_{L,i}} \right)^2 \leq 1 \quad (\text{Eqn. 3}),$$

$$\sum_{i=100 \text{ kHz}}^{2 \text{ GHz}} \left( \frac{H_i}{H_{L,i}} \right)^2 \leq 1 \quad (\text{Eqn. 4}),$$

838  
 839 and,

$$\sum_{i=30 \text{ MHz}}^{300 \text{ GHz}} \frac{S_{inc,i}}{S_{inc,L,i}} \leq 1 \quad (\text{Eqn. 5}),$$

841  
 842 where  $E_i$  is the electric field strength at frequency  $i$ ;  $E_{L,i}$  is the electric field reference level at  
 843 frequency  $i$  from Table 4;  $H_i$  is the magnetic field strength at frequency  $i$ ;  $H_{L,i}$  is the magnetic  
 844 field reference level at frequency  $i$  from Table 4;  $S_{inc,i}$  is the incident power density at  
 845 frequency  $i$ ; and  $S_{inc,L,i}$  is the incident power density reference level at frequency  $i$  from Tables  
 846 4 and 5.

847 For practical application of the basic restrictions, the following criteria regarding limb current  
 848 reference levels should be applied;

$$\sum_{i=100 \text{ kHz}}^{110 \text{ MHz}} \left( \frac{I_i}{I_{L,i}} \right)^2 \leq 1 \quad (\text{Eqn. 6}),$$

850  
 21

851 where  $I_i$  is the limb current component at frequency  $i$ ; and  $I_{L,i}$  is the limb current reference  
852 level (see Table 7).

### 853 5.4.3 Basic restrictions < 6 minutes

854 For time intervals < 6 minutes above 400 MHz, SA and transmitted energy density values  
855 should be added according to:

856

$$\sum_{i=400 \text{ MHz}}^{6 \text{ GHz}} \frac{SA_i}{SA_L} + \sum_{i>6 \text{ GHz}}^{300 \text{ GHz}} \frac{H_{tr,i}}{H_{tr,L}} \leq 1 \quad (\text{Eqn. 7}),$$

857  
858 where  $SA_i$  is the SA caused by exposure at frequency  $i$ ;  $SA_L$  is the SA limit given in Table 3;  
859  $H_{tr,i}$  is the transmitted energy density at frequency  $i$ ; and  $H_{tr,L}$  is the transmitted energy density  
860 limit given in Table 3.

### 861 5.4.4 Reference levels < 6 minutes

862 For practical application of the basic restrictions, the following criteria regarding reference  
863 levels of field strengths should be applied.

864

$$\sum_{i=400 \text{ MHz}}^{300 \text{ GHz}} \frac{H_{inc,i}}{H_{inc,L,i}} \leq 1 \quad (\text{Eqn. 8}),$$

865  
866 where  $H_{inc,i}$  is the incident energy density at frequency  $i$ ; and  $H_{inc,L,i}$  is the incident energy  
867 density reference level at frequency  $i$  from Table 6.

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