

3 RADIO FREQUENCY AND MICROWAVE 4 RADIATION SAFETY

5
6 NIST S7101.70

7 Approval Date: 01/12/2021

8 Effective Date:¹ 04/01/18
9

10 11 1. PURPOSE

12 The purpose of this program is to establish the requirements and associated roles and
13 responsibilities to minimize the risk of exposure to radio frequency (RF) and microwave (MW)
14 radiation (RF/MW, for short).
15

16 17 2. BACKGROUND

18 a. NIST P 7100.00: *Occupational Safety and Health* articulates NIST's commitment to making
19 occupational safety and health an integral core value and vital part of the NIST culture by, in
20 part:

21
22 (1) Complying with applicable laws, regulations, and other promulgated safety and health
23 requirements; and

24
25 (2) Abating deficiencies and taking actions to prevent incidents from occurring.
26

27 b. RF radiation is defined as electromagnetic waves with frequencies between 0.3 MHz and
28 300,000 MHz and includes MW radiation in the upper spectrum with frequencies between
29 300 MHz and 300,000 MHz.
30

31 c. As there are varying types of RF/MW radiation-generating **systems** (see Section 7,
32 **DEFINITIONS**), the general approach to RF/MW radiation safety is to define the quantities
33 that must be measured, and follow established maximum permissible exposure limits
34 (MPELs) for those quantities to assure that no adverse health effects will occur.

¹ For revision history, see Appendix A.

35 d. The nature and degree of the health effects of overexposure to an RF/MW radiation field
36 depend on the frequency and intensity of the field at the point of exposure, the part of the
37 body exposed, and the duration of the exposure. The intensity of the field at the point of
38 exposure depends on the distance from the source, any shielding that may be used, and
39 other factors.

40
41

42 3. APPLICABILITY

43 a. This suborder applies to all NIST employees and covered associates whose duties require
44 them to work with devices or systems intended to generate RF/MW radiation:

45

46 (1) In free space, or

47

48 (2) Inside enclosures that workers could enter,

49

50 who could be exposed to RF/MW radiation at levels that equal or exceed the occupational
51 MPELs specified in Section 6a.

52

53 b. This suborder does not apply to commercially available microwave ovens used in food
54 preparation.

55

56 c. This suborder does not apply to magnetic field generating equipment, both static and time
57 varying with frequencies up to 30 kilohertz (kHz). Refer to the Magnetic Field Safety
58 Suborder.

59

60

61 4. REFERENCES

62 a. 47 Code of Federal Regulations (CFR) 1.1310 – [Radiofrequency Exposure Limits \[Federal
63 Communications Commission \(FCC\)\]](#).

64

65 b. FCC Office of Engineering and Technology Bulletin 65 (August 1997), *Evaluating
66 Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic
67 Fields*.

68

69 c. Institute of Electronics and Electrical Engineers (IEEE) Standard C95.1-2005, IEEE
70 International Committee on Electromagnetic Safety (SCC39), *IEEE Standard for Safety
71 Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz
72 to 300 GHz*.

73

- 74 d. IEEE Standard C95.2-1999, IEEE International Committee on Electromagnetic Safety, *IEEE*
75 *Standard for Radio-Frequency Energy and Current Flow Symbols*.
76
77 e. IEEE Standard C95.3--2002, IEEE International Committee on Electromagnetic Safety
78 (SCC28), *IEEE Recommended Practice for the Measurement of Potentially Hazardous*
79 *Electromagnetic Fields - RF and Microwave*.
80
81 f. IEEE Standard C95.7-2014, IEEE International Committee on Electromagnetic Safety
82 (SCC28), *IEEE Recommended Practice for Radio Frequency Safety Programs, 3 kHz to 300*
83 *GHz*.
84
85 g. International Commission on Non-Ionizing Radiation Protection (ICNIRP), Guidelines for
86 Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (up to
87 300 GHz).
88
89

90 **5. APPLICABLE NIST OCCUPATIONAL SAFETY AND HEALTH SUBORDERS**

- 91 a. NIST S 7101.20: *Work and Worker Authorization Based on Hazard Reviews (Hazard*
92 *Review*)".
93
94 b. NIST S 7101-21: *Personal Protective Equipment*.
95
96 c. NIST S 7101.22: *Hazard Signage*.
97
98 d. NIST S 7101.23: *Safety Education and Training*.
99

100
101 **6. REQUIREMENTS**

- 102 a. Maximum Permissible Exposure Limits (MPELs) for RF/MW Radiation

103
104 (1) **Occupational exposures and general population exposures** (see Section 7,
105 **DEFINITIONS**) at NIST shall not exceed the MPELs adopted by the FCC². Please see
106 Tables 1 and 2 and Figures 1 and 2 for these MPELs.
107

² The FCC's limits are based on exposure limits recommended by the National Council on Radiation Protection and Measurements (NCRP), and over a wide range of frequencies, the exposure limits developed by IEEE and adopted by the American National Standards Institute (ANSI) to replace the 1982 ANSI guidelines. For additional information regarding the tables and figures, please refer to IEEE C95.1-2005

108 **Table 1: FCC MPELs for Occupational Exposures to RF/MW Radiation.**

Frequency Range (MHz)	RMS Electric Field Strength (E) (V/m)	RMS Magnetic Field Strength (H) (A/m)	RMS power density (S) E-field, H-field (W/m ²)	Averaging Time E ² , H ² or S (minutes)
0.1 – 1.0	1842	16.3/ <i>f_M</i>	(9000, 100 000/ <i>f_M</i> ²)	6
1.0 -30	1842/ <i>f_M</i>	16.3/ <i>f_M</i>	(9000/ <i>f_M</i> ² , 100 000/ <i>f_M</i> ²)	6
30 - 100	61.4	16.3/ <i>f_M</i>	(10, 100 000/ <i>f_M</i> ²)	6
100 - 300	61.4	0.163	10	6
300 – 3000	---	---	<i>f_M</i> /30	6
3000 – 30 000	---	---	100	19.63/ <i>f_G</i> ^{1.079}
30 000 – 300 000	---	---	100	2.524/ <i>f_G</i> ^{0.476}

Note: *f_M* is the frequency in MHz, *f_G* is the frequency in GHz.

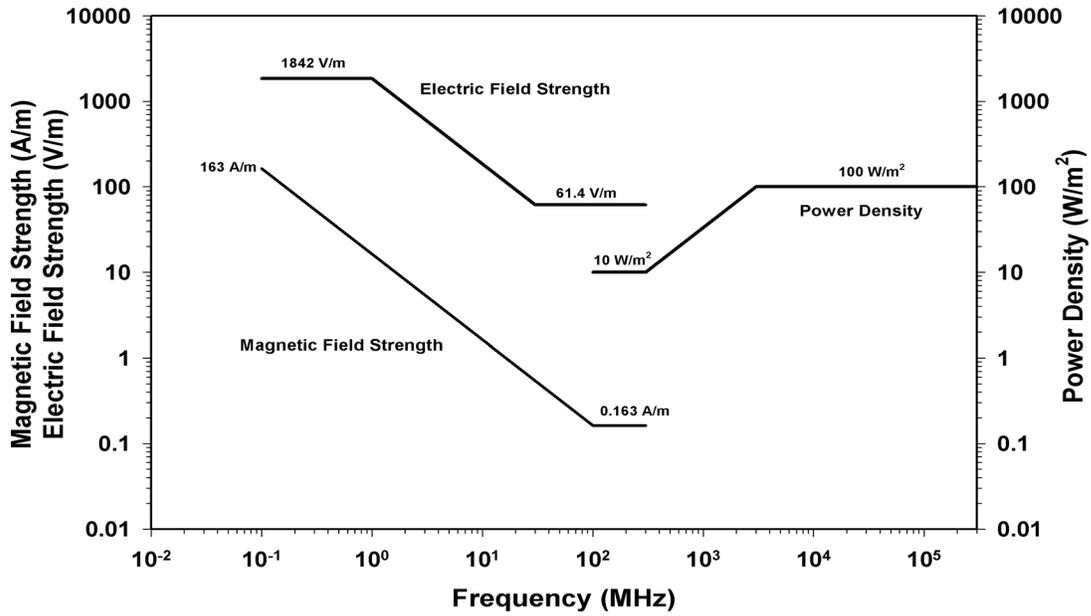
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110 **Table 2: FCC MPELs for General Population Exposures to RF/MW Radiation.**

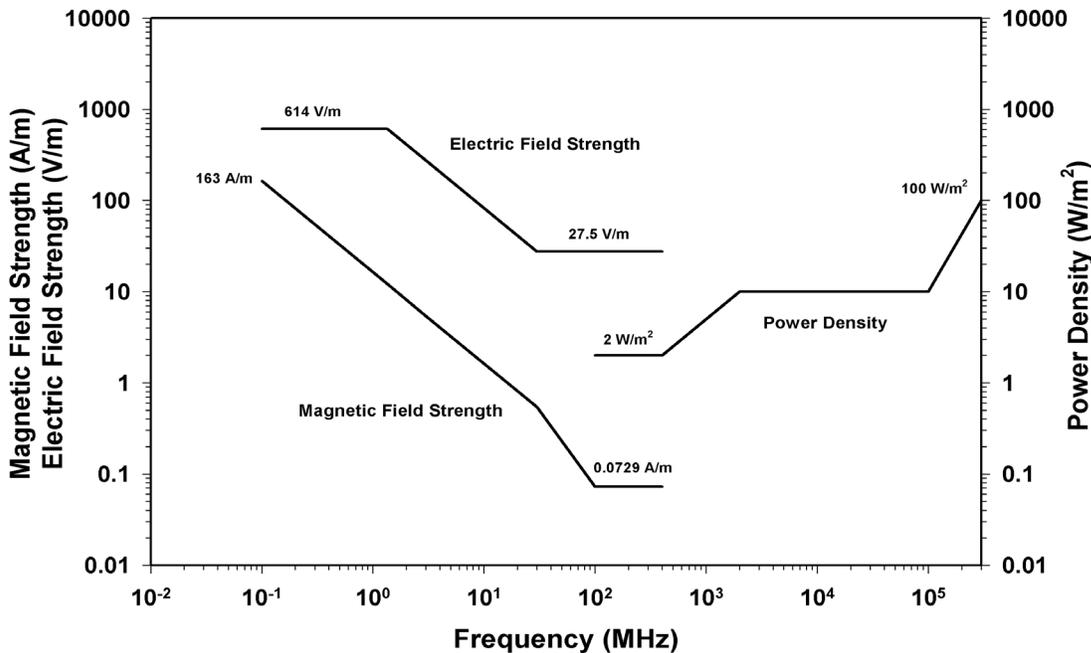
Frequency Range (MHz)	RMS Electric Field Strength (E) (V/m)	RMS Magnetic Field Strength (H) (A/m)	RMS power density (S) E-field, H-field (W/m ²)	Averaging time E ² , H ² or S (minutes)	
0.1 – 1.34	614	16.3/ <i>f_M</i>	(1000, 100 000/ <i>f_M</i> ²)	6	6
1.34 -3	823.8/ <i>f_M</i>	16.3/ <i>f_M</i>	(1800/ <i>f_M</i> ² , 100 000/ <i>f_M</i> ²)	<i>f_M</i> ² /0.3	6
3 - 30	823.8/ <i>f_M</i>	16.3/ <i>f_M</i>	(1800/ <i>f_M</i> ² , 100 000/ <i>f_M</i> ²)	30	6
30 - 100	27.5	158.3/ <i>f_M</i> ^{1.668}	(2, 9 400 000/ <i>f_M</i> ^{3.336})	30	0.0636 <i>f_M</i> ^{1.337}
100 – 400	27.5	0.0729	2	30	30
400 – 2000	---	---	<i>f_M</i> /200	30	
2000 – 5000	---	---	10	30	
5000 – 30 000	---	---	10	150/ <i>f_G</i>	
30 000 – 100 000	---	---	10	25.42/ <i>f_G</i> ^{0.476}	
100 000 – 300 000	---	---	(90 <i>f_G</i> -7000)/200	5048/[(9 <i>f_G</i> -700) <i>f_G</i> ^{0.476}]	

Note: *f_M* is the frequency in MHz, *f_G* is the frequency in GHz.

111



112
 113 **Figure 1: Graphical Representation of the MPEL's in Table 1 for Occupational Exposures**
 114 **to RF/MW Radiation.**
 115
 116



117
 118
 119 **Figure 2: Graphical Representation of the MPEL's in Table 2 for General Population**
 120 **Exposures to RF/MW Radiation.**

121 b. Control Measures

122

123 (1) Occupational Exposure Control Measures

124

125 (a) Control measures shall be enacted such that exposure shall not exceed the MPELs
126 specified in Table 1, or Figure 1, in accessible areas for those individuals covered by
127 the MPELs for occupational exposure. Appropriate control measures include, but are
128 not limited to:

129

130 i. Metal shielding;

131

132 ii. Interlocks;

133

134 iii. Physical barriers; and

135

136 iv. Signage (see **Appendix B** for signage examples);

137

138 (i) “Warning” signs shall be placed before reaching the boundaries of
139 areas beyond which the MPELs for occupational exposures *may* be
140 exceeded under certain circumstances.

141

142 (ii) “Danger” signs shall be placed before reaching the boundaries of areas
143 where MPELs for occupational exposures *will* be exceeded under
144 certain circumstances.

145

146 (b) Standard operating procedures, including techniques to measure potential RF/MW
147 radiation exposure, shall be written and adhered to for all experiments involving the
148 use of RF/MW radiation-generating systems that have the potential to exceed
149 established MPELs for occupational exposure.

150

151 i. RF/MW generating systems shall be evaluated for compliance with the
152 suborder requirements.

153

154 ii. Calculations may be used for establishing a basic idea of the field strength
155 present, however, measurements shall be required to specifically quantify
156 RF/MW exposure levels if the calculated results exceed one half of the
157 occupational exposure limits.

158

159 iii. Field strength probe may be used to measure RF Radiation levels. Consult
160 with RF/MW program manager for assistance.

- 161 iv. IEEE Standard C95.3-1991 should be consulted for appropriate measurement
162 techniques.
- 163
- 164 (c) Systems shall be operated remotely if the potential for exposure exceeds the
165 established MPELs for occupational exposure after all other engineering controls are
166 implemented.
- 167
- 168 (d) Systems shall have interlocked doors if exposure levels are above established MPELs
169 for occupational exposures and/or there is the potential of thermal burns.
- 170
- 171 (e) Personal protective equipment (PPE) may be used in addition to engineering controls
172 in place to reduce RF/MW radiation exposures. Manufacturers' recommendations on
173 adequate selection and use of PPE shall be followed.
- 174
- 175 (f) Transmit antennas shall be placed in locations where foot traffic is not permitted if
176 there is the potential for exposure to exceed the established MPELs for general
177 population exposure.
- 178
- 179 (g) Systems that are designed and constructed with a specific shielding effectiveness do
180 allow for radiated field strength levels that may exceed the MPELs. Some examples
181 of these systems are transverse electromagnetic (TEM) cells, gigahertz transverse
182 electromagnetic (GTEM) cells, reverberation chambers, and anechoic chambers. For
183 these types of system, no staff shall be permitted inside these cells or chambers
184 during operation. The use of controls such as standard operating procedures,
185 interlocks, on-the-job training, and the controls mentioned above, or a combination of
186 controls, shall be established to ensure staff safety.

187

188 (2) General Population Exposure Control Measures

189

- 190 (a) Control measures shall be enacted such that the general population exposure shall not
191 exceed the MPELs specified in Table 2 in accessible areas for those individuals not
192 covered by the occupational exposure limits. Appropriate control measures include,
193 but are not limited to:
- 194
- 195 i. Physical barriers; and
- 196
- 197 ii. Signage (see **Appendix B** for signage examples):
- 198

199 (i) “Caution” signs shall be placed before reaching the boundaries of
200 areas beyond which the MPELs for the general population *may* be
201 exceeded under certain circumstances.
202

203 d. Training

204
205 (1) Training shall be provided, documented, and recorded in accordance with the
206 requirements of NIST S 7101.23: *Safety Education and Training*.

207
208 (2) Employees and covered associates to whom the requirements of this suborder apply shall
209 complete the following:

210
211 (a) The training provided by OSHE on the RF/MW Radiation Safety Program; and

212
213 (b) The activity-specific training, provided -within their Organizational Units (OUs),
214 determined as required by applicable hazard reviews.

215
216 (3) The official first-level supervisors of employees and covered associates to whom the
217 requirements of this suborder apply shall complete the training provided by OSHE on the
218 RF/MW Radiation Safety Program.
219

220
221 **7. DEFINITIONS**

222 a. Contact Current – Current induced in a biological medium via a contacting electrode or other
223 source of current.
224

225 b. Electric Field – A field vector quantity that represents the force (F) on a positive test charge
226 (q) at a point, divided by the charge: $E = F/q$. Electric field strength is expressed in units of
227 volts per meter (V/m).
228

229 c. Exposure – For the purposes of this subject matter area, the subjection of a person to electric,
230 magnetic, or electromagnetic fields or to contact currents other than those originating from
231 physiological processes in the body and other natural phenomena.
232

233 d. General Population Exposure – Exposure of an individual whose duties do not require them
234 to work with RF/MW radiation-generating systems to RF/MW radiation.
235

236 e. Hertz – The unit for expressing frequency (f). One hertz (Hz) equals one cycle per second.
237

- 238 f. Magnetic Field Strength (H) – A vector that is equal to the magnetic flux density divided by
239 the permeability of the medium. Magnetic field strength is expressed in units of amperes per
240 meter (A/m).
241
- 242 g. Maximum Permissible Exposure Limits (MPELs) – Derived limits in radiofrequency
243 exposure standards for time averaged and peak exposures to ambient electric (E) and
244 magnetic (H) fields, *e.g.*, the root-mean-square (rms) or peak electric and magnetic field
245 strengths, their squares, or the plane-wave equivalent power densities associated with these
246 fields, and the induced and contact currents and contact voltages to which a person may be
247 exposed without harmful effect.
248
- 249 h. Occupational Exposure – Exposure of an individual whose duties require them to work with
250 RF/MW radiation-generating systems to RF/MW radiation.
251
- 252 i. Power Density (S) or Electric Power Flux Density – Power per unit area normal to the
253 direction of propagation. This is usually expressed in units of watts per square meter (W/m^2)
254 or milliwatts per square centimeter (mW/cm^2). For plane wave power density, electric field
255 strength (E) and magnetic field strength (H) are related by the impedance of free space, *i.e.*,
256 377 ohms. That is, $S = E^2 / 377$ or $377H^2$, where S is in units of W/m^2 when E and H are
257 expressed in units of V/m and A/m respectively. Although many survey instruments indicate
258 power density units, the actual quantities measured are E or E^2 or H or H^2 .
259
- 260 j. System – For the purposes of this suborder, a system is a composition of multiple devices or
261 pieces of equipment that independently would not have the potential to exceed established
262 MPELs for occupational exposure as per Table 1, but together have the potential to exceed
263 the MPELs.
264
265

266 8. ACRONYMS

- 267 a. CFR – Code of Federal Regulations
268
- 269 b. FCC – Federal Communications Commission
270
- 271 c. MPELs – Maximum Permissible Exposure Limits
272
- 273 d. RF/MW – Radiofrequency and Microwave
274
- 275 e. RMS – Root-mean-square
276
- 277 f. IEEE – Institute of Electronics and Electrical Engineers

278 g. OSHE – Office of Safety, Health, and Environment

279

280 h. OU – Organizational Unit

281

282

283 **9. RESPONSIBILITIES**

284 Roles and responsibilities common to all NIST safety and health suborders can be found in NIST

285 O 7100.00. The roles and responsibilities specific to this suborder are as follows:

286

287 a. OU Directors:

288

289 (1) Ensuring that the requirements of this suborder are met in their OU.

290

291 b. NIST Employees and Covered Associates to Whom the Requirements of this Suborder
292 Apply:

293

294 (1) Completing the training required by this program and their OUs/divisions; and

295

296 (2) Adhering to the requirements for working with RF/MW radiation-generating systems as
297 delineated in this document.

298

299 c. Official First-Level Supervisors of Employees and Covered Associates to Whom the
300 Requirements of this Suborder Apply:

301

302 (1) Completing the training provided by OSHE on the RF/MW Radiation Safety Program.

303

304 d. Chief Safety Officer:

305

306 (1) Appointing an OSHE staff member to serve as the NIST Radiofrequency and Microwave
307 Safety Officer to carry out the responsibilities for this position delineated below.

308

309 e. Radiofrequency Safety Officer:

310

311 (1) Assisting in the following areas, as requested:

312

313 (a) Evaluating RF/MW radiation hazards, including performing measurements to
314 quantify RF/MW radiation exposure levels;

315

316 (b) Evaluating adequacy of control measures;

317

318 (c) Recommending substitute or alternate controls; and

319

320 (d) Ensuring survey equipment owned by OSHE is calibrated per manufacturer
321 specifications.

322

323

324 **10. AUTHORITIES**

325 There are no authorities specific to this suborder alone.

326

327

328 **11. DIRECTIVE OWNER**

329 Chief Safety Officer

330

331

332 **12. APPENDICES**

333 A. Revision History

334

335 B. Signage

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337

338

Appendix A. Revision History

339

Revision No.	Approval Date	Person Responsible	Brief Description of Change; Rationale
0	11/09/17	TBD	<ul style="list-style-type: none">• None – Initial document
1	1/12/21	April Camenisch	<ul style="list-style-type: none">• Updated NIST Suborder links.

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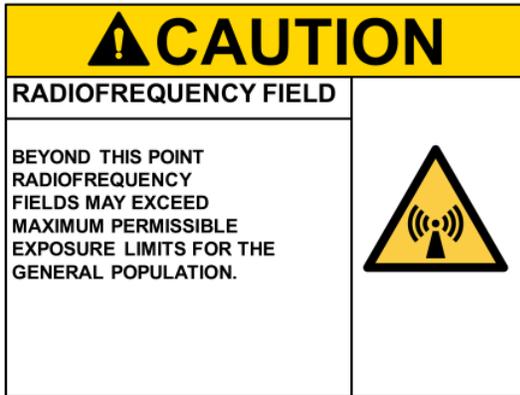
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Appendix B. Signage

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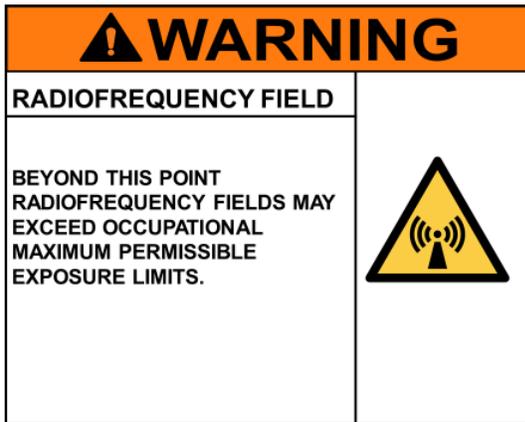
344 a. Caution:



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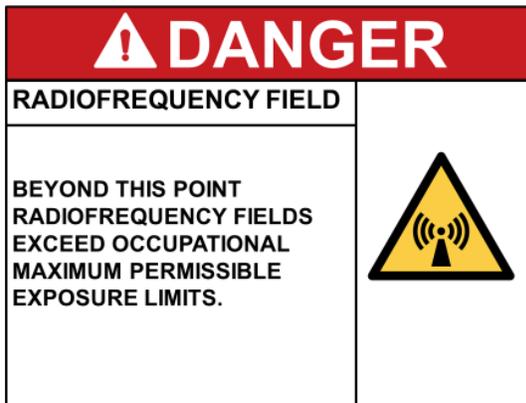
347 b. Warning:



348

349

350 c. Danger:



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