

RADIO FREQUENCY AND MICROWAVE RADIATION SAFETY

NIST S7101.70

Approval Date: 01/12/2021

Effective Date:¹ 04/01/18

1. PURPOSE

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

2. BACKGROUND

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

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

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

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

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

¹ For revision history, see Appendix A.

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

3. APPLICABILITY

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

(1) In free space, or

(2) Inside enclosures that workers could enter,

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

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

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

4. REFERENCES

- a. 47 Code of Federal Regulations (CFR) 1.1310 – [Radiofrequency Exposure Limits \[Federal Communications Commission\]](#) (FCC)].
- b. FCC Office of Engineering and Technology Bulletin 65 (August 1997), *Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields*.
- c. Institute of Electronics and Electrical Engineers (IEEE) Standard C95.1-2005, IEEE International Committee on Electromagnetic Safety (SCC39), *IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz*.

- d. IEEE Standard C95.2-1999, IEEE International Committee on Electromagnetic Safety, *IEEE Standard for Radio-Frequency Energy and Current Flow Symbols*.
- e. IEEE Standard C95.3--2002, IEEE International Committee on Electromagnetic Safety (SCC28), *IEEE Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields - RF and Microwave*.
- f. IEEE Standard C95.7-2014, IEEE International Committee on Electromagnetic Safety (SCC28), *IEEE Recommended Practice for Radio Frequency Safety Programs, 3 kHz to 300 GHz*.
- g. International Commission on Non-Ionizing Radiation Protection (ICNIRP), Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (up to 300 GHz).

5. APPLICABLE NIST OCCUPATIONAL SAFETY AND HEALTH SUBORDERS

- a. NIST S 7101.20: *Work and Worker Authorization Based on Hazard Reviews (Hazard Review)*.
- b. NIST S 7101-21: *Personal Protective Equipment*.
- c. NIST S 7101.22: *Hazard Signage*.
- d. NIST S 7101.23: *Safety Education and Training*.

6. REQUIREMENTS

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

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

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	$16.3/f_M$	$(9000, 100\,000/f_M^2)$	6
1.0 -30	$1842/f_M$	$16.3/f_M$	$(9000/f_M^2, 100\,000/f_M^2)$	6
30 - 100	61.4	$16.3/f_M$	$(10, 100\,000/f_M^2)$	6
100 - 300	61.4	0.163	10	6
300 – 3000	---	---	$f_M/30$	6
3000 – 30 000	---	---	100	$19.63/f_G^{1.079}$
30 000 – 300 000	---	---	100	$2.524/f_G^{0.476}$

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	$16.3/f_M$	$(1000, 100\,000/f_M^2)$	6	6
1.34 -3	$823.8/f_M$	$16.3/f_M$	$(1800/f_M^2, 100\,000/f_M^2)$	$f_M^2/0.3$	6
3 - 30	$823.8/f_M$	$16.3/f_M$	$(1800/f_M^2, 100\,000/f_M^2)$	30	6
30 - 100	27.5	$158.3/f_M^{1.668}$	$(2, 9\,400\,000/f_M^{3.336})$	30	$0.0636f_M^{1.337}$
100 – 400	27.5	0.0729	2	30	30
400 – 2000	---	---	$f_M/200$	30	
2000 – 5000	---	---	10	30	
5000 – 30 000	---	---	10	$150/f_G$	
30 000 – 100 000	---	---	10	$25.42/f_G^{0.476}$	
100 000 – 300 000	---	---	$(90f_G-7000)/200$	$5048/[(9f_G-700)f_G^{0.476}]$	

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

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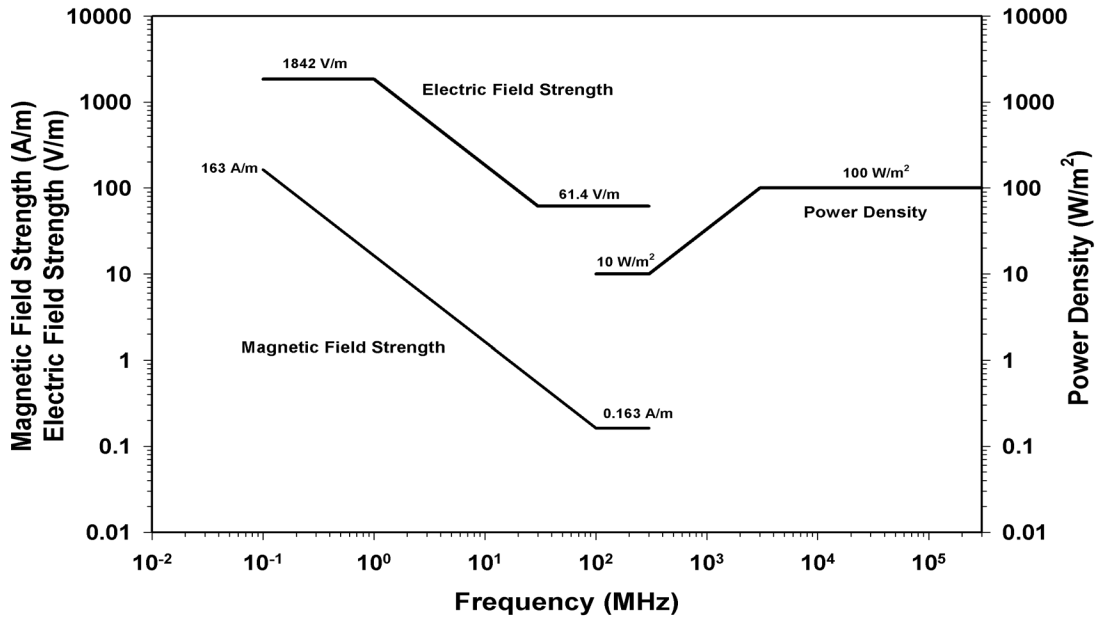


Figure 1: Graphical Representation of the MPEL's in Table 1 for Occupational Exposures to RF/MW Radiation.

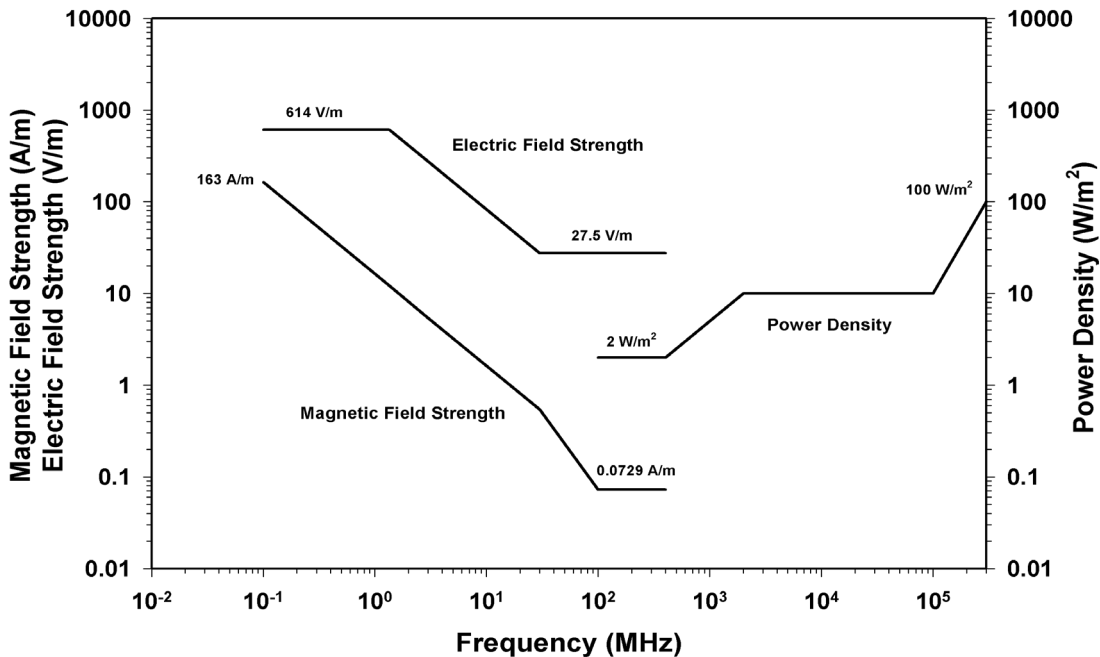


Figure 2: Graphical Representation of the MPEL's in Table 2 for General Population Exposures to RF/MW Radiation.

b. Control Measures

(1) Occupational Exposure Control Measures

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

i. Metal shielding;

ii. Interlocks;

iii. Physical barriers; and

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

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

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

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

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

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

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

iv. IEEE Standard C95.3-1991 should be consulted for appropriate measurement techniques.

(c) Systems shall be operated remotely if the potential for exposure exceeds the established MPELs for occupational exposure after all other engineering controls are implemented.

(d) Systems shall have interlocked doors if exposure levels are above established MPELs for occupational exposures and/or there is the potential of thermal burns.

(e) Personal protective equipment (PPE) may be used in addition to engineering controls in place to reduce RF/MW radiation exposures. Manufacturers' recommendations on adequate selection and use of PPE shall be followed.

(f) Transmit antennas shall be placed in locations where foot traffic is not permitted if there is the potential for exposure to exceed the established MPELs for general population exposure.

(g) Systems that are designed and constructed with a specific shielding effectiveness do allow for radiated field strength levels that may exceed the MPELs. Some examples of these systems are transverse electromagnetic (TEM) cells, gigahertz transverse electromagnetic (GTEM) cells, reverberation chambers, and anechoic chambers. For these types of system, no staff shall be permitted inside these cells or chambers during operation. The use of controls such as standard operating procedures, interlocks, on-the-job training, and the controls mentioned above, or a combination of controls, shall be established to ensure staff safety.

(2) General Population Exposure Control Measures

(a) Control measures shall be enacted such that the general population exposure shall not exceed the MPELs specified in Table 2 in accessible areas for those individuals not covered by the occupational exposure limits. Appropriate control measures include, but are not limited to:

i. Physical barriers; and

ii. Signage (see **Appendix B** for signage examples):

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

d. Training

- (1) Training shall be provided, documented, and recorded in accordance with the requirements of NIST S 7101.23: *Safety Education and Training*.
- (2) Employees and covered associates to whom the requirements of this suborder apply shall complete the following:
- (a) The training provided by OSHE on the RF/MW Radiation Safety Program; and
- (b) The activity-specific training, provided -within their Organizational Units (OUs), determined as required by applicable hazard reviews.
- (3) The official first-level supervisors of employees and covered associates to whom the requirements of this suborder apply shall complete the training provided by OSHE on the RF/MW Radiation Safety Program.

7. DEFINITIONS

- a. Contact Current – Current induced in a biological medium via a contacting electrode or other source of current.
- b. Electric Field – A field vector quantity that represents the force (F) on a positive test charge (q) at a point, divided by the charge: $E = F/q$. Electric field strength is expressed in units of volts per meter (V/m).
- c. Exposure – For the purposes of this subject matter area, the subjection of a person to electric, magnetic, or electromagnetic fields or to contact currents other than those originating from physiological processes in the body and other natural phenomena.
- d. General Population Exposure – Exposure of an individual whose duties do not require them to work with RF/MW radiation-generating systems to RF/MW radiation.
- e. Hertz – The unit for expressing frequency (f). One hertz (Hz) equals one cycle per second.

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

8. ACRONYMS

- a. CFR – Code of Federal Regulations
- b. FCC – Federal Communications Commission
- c. MPELs – Maximum Permissible Exposure Limits
- d. RF/MW – Radiofrequency and Microwave
- e. RMS – Root-mean-square
- f. IEEE – Institute of Electronics and Electrical Engineers

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

h. OU – Organizational Unit

9. RESPONSIBILITIES

Roles and responsibilities common to all NIST safety and health suborders can be found in NIST O 7100.00. The roles and responsibilities specific to this suborder are as follows:

a. OU Directors:

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

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

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

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

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

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

d. Chief Safety Officer:

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

e. Radiofrequency Safety Officer:

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

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

(b) Evaluating adequacy of control measures;

318 (c) Recommending substitute or alternate controls; and

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

325 There are no authorities specific to this suborder alone.
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328 **11. DIRECTIVE OWNER**

329 Chief Safety Officer
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332 **12. APPENDICES**

333 A. Revision History
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335 B. Signage
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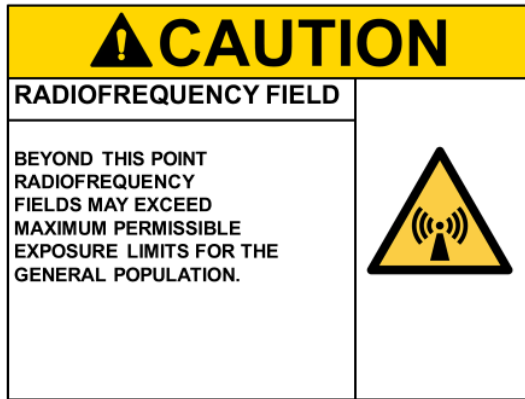
Appendix A. Revision History

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.

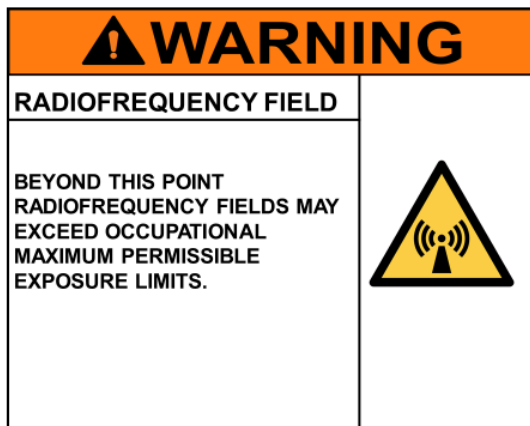
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Appendix B. Signage

a. Caution:



b. Warning:



c. Danger:

