FESHM 4320: RADIO FREQUENCY HAZARDS

Revision History

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Matthew Spaw	Initial Release	June 2020

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1.0 INTRODUCTION AND SCOPE

Radiofrequency (RF) radiation is electromagnetic radiation (EMR) at the frequency range of 30 kilohertz (kHz) to 300 GHz. This includes microwave radiation (300 MHz – 300 GHz), which is a region of the RF spectrum. At certain power-density levels RF radiation can be hazardous. The hazards are associated with the heating of biological tissue, which occurs when EM radiation is absorbed by the body.

This program applies to equipment capable of emitting RF radiation including klystrons and waveguide systems, communication transmitters, induction heaters, and ultrasonic cleaners. Consumer items such as microwave ovens and cellphones are exempted. It applies to all Fermilab personnel, experimenters, temporary employees, users and subcontract/term employees working at Fermilab and any leased spaces.

2.0 DEFINITIONS

Electric Field Strength (E) – 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).

Electromagnetic radiation (EMR) – energy in the form of transverse magnetic and electric waves including microwaves and radio waves

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).

Maximum Permissible Exposure (MPE) – the highest rms or peak electric or magnetic field strengths, their squares, or the plane-wave equivalent power densities with these fields, or induced and contact currents to which a person may be exposed without incurring an established adverse health effect and with an acceptable margin of safety.

Microwave - any of the electromagnetic wave frequencies that lie in the range extending from 300 MHz – 300 GHz.

Power Density (S) – power per unit area normal to the direction of propagation. This is usually expressed in units of watts per square meter (W/m^2).

Radiofrequency (RF) – any of the electromagnetic wave frequencies that lie in the range extending from 30 kHz – 300 GHz.

Root-Mean-Square (rms) – effective value, or the value associated with the joule heating, of a periodic electromagnetic wave. The rms value is obtained by taking the square root of the mean of the squared value of a function. Note: most meter provide rms values directly.

Spatial Averaging – the rms of the field over an area equivalent to the vertical cross section of the adult human body, as applied to the measurement of electric or magnetic fields in the assessment of whole-body exposure. This is accomplished by measuring a planar area equivalent to the area occupied by a standing adult human from 0-2m.

Specific Absorption Rate – is a measure of the rate at which energy is absorbed by the human body when exposed to a radio frequency electromagnetic field. It is defined as the power absorbed per mass of tissue and has units of watts per kilogram (W/kg).

Threshold Limit Value (TLV) – the occupational exposure limit under which it is believed that nearly all healthy workers may be repeatedly exposed, day after day, without adverse health effects.

3.0 RESPONSIBILITIES

Division Safety Officer (DSO) – Work with potentially-exposed personnel, managers, and ES&H in assessing exposures, designing controls, training, and providing signs and labels

Supervisor – Know and understand the potential RF hazards in their work area. Document required job-specific training and work procedures related to RF hazards. Ensure workers understand RF hazards in their work area. Assist in identifying potential exposures and in implementing any necessary controls. Supervisors have a key role in assuring that their workers adhere to requisite behaviors.

ES&H – Assist affected divisions/sections/projects in providing technical advice in this chapter, assessing exposures, designing controls, training, and providing signs and labels.

Fermilab Occupational Medical Office -Provide guidance to workers on potential hazards of RF radiation and interference with electronic medical devices, if requested. In the event of a known or suspected RF overexposure, conduct and exam and arrange for further exams as necessary.

Worker – Assist in identifying potential exposures and in implementing any necessary controls. Adhere to requisite safety behaviors.

4.0 PROCEDURES

New or modified installations shall undergo an Industrial Hygiene Assessment with the equipment owner. Modified installations include those that have undergone changes to a previously surveyed environment that may affect human exposure, and those where levels of emitted power have changed. Following an Industrial Hygiene Assessment, ESH will determine if an Industrial Hygiene Survey is necessary.

4.1 Industrial Hygiene Survey

Depending on the frequency, a survey to determine Electronic Field Strength (E), Magnetic Field Strength (H), or Power Density (S) is performed using appropriate survey meters by the Industrial

Hygiene Group or another trained individual designated by ES&H. Measurements shall be performed with an RF survey meter calibrated according to manufacturer specifications. To request an industrial hygiene survey, contact your DSO.

4.2 Controlling Occupational Exposures

Engineering control in accordance with IEEE/ANSI C95.1 should be the primary method used to restrict exposure, whenever practical. If engineering controls are not practical, work-time limits, based on the averaging intervals and other work-practice and administrative controls, shall be used including:

1. Hazard Signs – Signs commensurate with the RF level should be used to inform personnel of RF hazards. These signs shall be posted on access panels of RF enclosures and at entrances to and inside regulated areas.
2. Access Limitation – Access can be limited by controls, such as barriers, interlocks, administrative controls, or other means. The operation supervisor controls access to regulated areas and shall approve non-routine entry of personnel into these places. When practical, sources of RF radiation should be switched off when not in use.
3. Shielding – Shielding that encloses the radiating equipment or provides a barrier between the equipment and the worker may be used to protect personnel. The shielding design should account for the frequency and strength of the field.
4. Interlocks – Chamber or oven-type equipment that uses microwave radiation shall have interlocks designed to (a) prevent generation of the radiation, unless the chamber is sealed, and (b) shut off such equipment, if the door is opened.
5. Lockout/Tagout – The design should incorporate features that allow the equipment to be locked out and tagged out for servicing.
6. PPE – PPE, such as eyewear is not readily available and is typically not a useful option as protection against RF radiation and fields. Protection should, therefore, be achieved by other means. For touch contact with conductive objects, the use of protective gloves may assist in reducing exposures.

4.3 Occupational Exposure Limits

Fermilab relies on Occupational Exposure Limits (OELs) established by the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs) for guidance in limiting RF hazards. The TLVs were designed to limit electrostimulation of nerve and muscle tissue at frequencies from 0.03 MHz to 0.1 MHz, and tissue heating above 0.1 MHz. The TLVs are based upon the belief that the primary, adverse physiological effects of electromagnetic energy in the 30 kHz – 300 GHz wavelength and frequency region are thermal. However, reported nonthermal biological effects were also considered.

The ACGIH TLV guidance is based on the nationally recognized consensus IEEE/ANSI standards for personnel exposure to radio-frequency radiation. Specific standards referenced are as follows:

- C95.3-2002, *Recommended Practice for Measurements and Computations of Radiofrequency Electromagnetic Fields with Respect to Human Exposure to Such Fields, 100kHz-300GHz*

- C95.1-2005, *Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz*.

4.3.1. ACGIH TLV

A. For exposures to electric and magnetic free fields, TLVs in Table 1, Part A refer to exposure values obtained by spatially averaging over an area equivalent to the vertical cross-section of the human body (projected area). In the case of partial body exposure, the TLVs can be relaxed. In nonuniform fields, spatial peak values of field strength may exceed the TLVs if the spatially averaged specific absorption rate (SAR) value remains within the specified limits.

B. Access should be restricted to limit the rms RF body current and potential for RF electrostimulation ("shock," below 0.1 MHz) or perceptible heating (at or above 0.1 MHz) as follows (see Table 1, Part B:

1. For free standing individuals (no contact with metallic objects), RF current induced in the human body, as measured through either foot, should not exceed the following values, where f is the frequency in MHz:
    i. **I** = 1000 f mA for (0.03 < f < 0.1 MHz) averaged over 0.2 s; where mA = milliampere
    ii. **I** = 100 mA for (0.1 < f < 100 MHz) averaged over 6 min
2. For conditions of possible contact with metallic bodies, the maximum RF current that can be passed into the body as measured with a contact current meter should not exceed the following values:
    i. **I** = 1000 f mA for (0.03 < f< 0.1 MHz) (where f is the frequency in MHz) averaged over 0.2 s
    ii. **I** = 100 mA for (0.1 < f < 100 MHz) averaged over 6 min

Table 1. Radiofrequency and Microwave TLVs

Part A – Electromagnetic Fields[A] (f = frequency in MHz)

Frequency	Power Density, S (W/m^2)	Electric Field Strength, E (V/m)	Magnetic Field Strength, H (V/m)	Averaging Time E^2, H^2, or S (min)
30 kHz – 100 kHz		1842	163	6
100 kHz – 1 MHz		1842	16.3/f	6
1 MHz – 30 MHz		1842/f	16.3/f	6
30 MHz – 100 MHz		61.4	16.3/f	6
100 MHz – 300 MHz	10	61.4	16.3/f	6
300 MHz – 3 GHz	f/30			6
3 GHz – 30 GHz	100			$34000/f^{1.079}$
30 GHz – 300 GHz	100			$68/f^{0.476}$

[A]The exposure values in terms of electric and magnetic field strengths are obtained by spatially averaging over an area equivalent to the vertical cross-section of the human body (projected area). At frequencies between 100 MHz and 300 MHz, the TLV is defined in the near field of the source in terms of electric and magnetic field, and in the far field in terms of the power density of the wave. At frequencies above 30 GHz, the power density TLV is the limit of exposure averaged over any contiguous 0.01 m^2 of body surface. However, above 30 GHz the maximum power density is 1000 W/m^2 in any one square centimeter.

Part B – Maximum Induced and Contact Radiofrequency Currents (mA)[B]

Frequency	Through Both Feet	Through Either Foot	Grasping[B1]	Average Time
30 kHz – 100 kHz	2000 f	1000 f	1000 f	0.2 s[C]
100 kHz – 100 MHz	200	100	100	6 min[D]

[B] It should be noted that the current limits given above may not adequately protect against startle reactions and burns caused by transient discharges when contacting an energized object.

The ceiling value for induced and contact currents is 500 mA for no more than 15 s per 6 min period.

[B1] Maximum Touch current is limited to 50% of the maximum grasping current.

[C] **I** is averaged over a 0.2 s period.

[D] **I** is averaged over a 6-minute period (e.g. for either foot or hand contact, i.e. **I** t<60,000 mA^2-min). In this table, f is the frequency in Hz.

3. For touch contact with conductive objects, the maximum RF current should not exceed more than one - half of the maximum RF current for grasping contact. The means of compliance with these current limits can be determined by the user of the TLVs as appropriate. The use of protective gloves, the avoidance of touch contact with conductive objects, the prohibition of metallic objects, or training of personnel may be sufficient to

ensure compliance with these TLV. Evaluation of the magnitude of the induced currents will normally require a direct measurement. However, induced and contact current measurements are not required if the spatially averaged electric field strength does not exceed the TLV given in Table 1, Part A at frequencies between 0. 1 and 100 MHz, as shown graphically in Figure 2.

C. For source frequencies greater than 100 MHz, Table 1, Part A provides an equivalent plane - wave power density, S (in W/m^2), which can be calculated from field strength measurement data as follows: $S = E^2/377$ where E^2 is in volts squared (V^2) per meter squared (m^2); and $S=377H^2$ where H^2 is in amperes squared (A^2) per meter squared (m^2).

D. For exposures to pulsed fields of pulse duration less than 100 milliseconds (ms) at frequencies in the range 0.1 MHz to 300 GHz, the total incident energy density during any 100 ms period within the averaging time (see Table 1. Part A) shall not exceed 20% of the total specific energy absorption (SA) permitted during the entire averaging time for a continuous field, i.e. 0.2 x 144 = 28.8 J/kg. For pulse durations greater than 100 ms, normal time-averaging calculations apply.

4.4 Limits for General Population/Uncontrolled Exposure

Areas that are accessible to the public in which measurements are above the MPE (see Table 2) and cannot be mitigated will be restricted and marked by appropriate warning signs. Table 2 below details the Maximum Permissible Exposure (MPE) for General Population/Uncontrolled Exposure as defined by the FCC OET Bulletin 65.

Table 2. MPE for General Population/Uncontrolled Exposure

Frequency (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time E^2, H^2, or S (min)
0.3 – 1.34	614	1.63	(100)*	30
1.34 – 30	824/f	2.19/f	($180/f^2$)*	30
30 – 300	27.5	0.073	0.2	30
300 – 1500	--	--	f/1500	30
1500 – 100,000	--	--	1.0	30
f = frequency		*Plane-wave equivalent power density		

4.5 Medical Device Consideration

The greatest concern about RF fields in terms of potential impacts on human health is the vulnerability of many electronic medical devices either worn by patients or used in clinical practices. RF field problems have been associated with the incorrect operation of cardiac pacemakers, defibrillators, drug infusion pumps, apnea monitors, and a diversity of other medical devices such as nerve stimulators, electrically powered wheelchairs, and motorized scooters.

Some medical devices are vulnerable to RF field levels less than the TLVs for RF-microwave radiation. Based on the available technical information and guidance from IEC and FDA-CDRH, ACGIH recommends that medical electronic equipment or the entry of individuals wearing medical devices subject to RF fields should be restricted to locations where the strength of RF fields at frequencies up to 3 GHz is not expected to interfere with operation of the devices based on manufacturers' specifications (typically field levels less than 3 to 10 V/m that meet RF field compliance requirements).

4.6 RF Hazard Signage

RF hazard signage is chosen on a case by case basis at the direction of ESH following an Industrial Hygiene Assessment or Survey. The sign signal word (i.e. DANGER, WARNING, etc.) and text message will reflect the health risk to exposed workers from the hazard. If you would like to determine if an area or piece of equipment needs RF hazard related signage reach out to your Division Safety Officer.

5.0 REFERENCES

1. **American Conference of Governmental Industrial Hygienists.** *2020 TLVs and BEIs.* Cincinnati : s.n., 2020. pp. 140-145.
2. **U.S. Department of Energy.** *DOE HANDBOOK ELECTRICAL SAFETY.* DOE-HDBK-1092-2013. Washington, D.C. : s.n., 2013.
3. **Federal Communications Commission Office of Engineering & Technology.** *Evaluating Compliance with FCC Guidelines for Human Exposure to RadioFrequency Electromagnetic Fields.* 97-01. Washington, D.C. : s.n., 1997.
4. **American Conference of Governmental Industrial Hygienists.** *Radiofrequency/Microwave Radiation: TLV(R) Physical Agents 7th Edition Documentation.* [PDF] Cincinnati : ACGIH, 2010. 7DOC-654.