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ES&H manual

Environment, Safety, and Health

Volume II

Part 20: Ionizing Radiation/Nonionizing Radiation

20.7 Nonionizing Radiation and Fields (Electromagnetic Fields and Radiation with Frequencies Below 300 GHz)

(Formerly H&SM S26.12)

Recommended for approval by the ES&H Working Group

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New document or new requirements

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20.7

Nonionizing Radiation and Fields
(Electromagnetic Fields and Radiation with Frequencies Below 300 GHz)*

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* **Minor revision**

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1.0 Introduction

1.1 Purpose and Scope

This document adopts the philosophy of Document 10.2, "LLNL Health Hazards Communication Program," in the *Environment, Safety, and Health (ES&H) Manual*. Its intent is to ensure that nonionizing radiation sources are identified and posted, users are properly trained to work with and around these sources, and measurements are taken to evaluate worker exposures. Controls to mitigate hazards are implemented when surveys indicate that exposures can exceed acceptable limits.

This document covers

- Static (dc) magnetic and electric fields.
- Extremely low-frequency fields with frequencies below 300 Hz, including power-line fields at 60 Hz.
- Radio-frequency (rf) fields and radiation with frequencies below 300 MHz.
- Microwave radiation with frequencies between 300 MHz and 300 GHz.

The bands of nonionizing radiation and fields addressed in this document are shown in Table 1.

Voltage, also called electromotive force, causes electrically charged particles to move against the resistance in the wiring of a circuit. Voltage can be created mechanically using a dynamo and chemically using batteries, as well as by friction and other means. Imposing a voltage on any object creates an electric field that extends into the space around the object. If the intensity of the voltage varies with time, the intensity of the electric field around the object also varies with time. The strength of the electric field around an object increases as the voltage imposed on the object increases. An electric field will induce charges to move in any object in which current can flow, including our bodies.

Table 1. Bands of radio-frequency and subradio-frequency fields and radiation.

Frequency Range	Wavelength Range	Name
>300 GHz	<1 mm	Infrared*
30 GHz—300 GHz	10 mm—1 mm	Extremely high frequency (EHF)
>3 GHz—30 GHz	10 cm—1 cm	Superhigh frequency (SHF)
300 MHz—3 GHz**	1 m —10 cm	Ultra high frequency (UHF)
30 MHz—300 MHz	10 m—1 m	Very high frequency (VHF)
3 MHz—30 MHz	100 m—10 m	High frequency (HF)
300 kHz—3 MHz	1 km—100 m	Medium frequency (MF)
30 kHz—300 kHz	10 km—1 km	Low frequency (LF)
3 kHz—30 kHz	100 km—10 km	Very low frequency (VLF)
300 Hz—3 kHz***	1000 km—100 km	Voice frequency
>0****—300 Hz	≥1000 km	Extremely low frequency (ELF)
0 Hz	—	Static

* See Document 11.2, "Hazards-General and Miscellaneous," in the *ES&H Manual* for guidance about infrared energy or Document 20.8, "Lasers," in the *ES&H Manual* for guidance about infrared laser energy.

** Frequencies>300 MHz up to 300 GHz are referred to as "microwaves".

*** Frequencies >3000 kHz up to 300 GHz are referred to as "radiofrequencies". Lower frequencies are referred to as "subradiofrequencies".

**** A traditional definition of extremely low frequencies was frequencies between 30 Hz and 300 Hz.

The flow of current creates a second field capable of influencing objects at a distance from the object in which current is flowing. This is the magnetic field. Its strength varies as the strength of the current creating it varies. A magnetic field that varies with time will cause electric current to flow in any conductor as the magnetic field changes. As human tissue is a conductor, a magnetic field that changes strength over time will cause current to flow in a human body. Stronger magnetic fields will induce more current flow. If the magnetic field does not change strength with time (i.e., a static magnetic field), interactions will occur with moving objects and with charged fluids in motion, such as blood flowing in the body. Magnetic fields decrease very rapidly with distance.

Electric and magnetic fields can exist separately or as a combined entity known as electromagnetic radiation.

The combined fields of electromagnetic radiation vary in strength over time and move at a fixed speed very close to 300,000,000 meters per second (about 186,000 miles per second) in open space and air. Since the fields are changing strength over time and the combination moves at a fixed speed, the energy can be defined by how often the fields change strength per second. This is defined as the frequency and is the fundamental description of electromagnetic radiation. The unit of frequency is "hertz," the number of field strength changes that occur in a second.

The distance between field strength changes is figured by dividing the speed of travel by the frequency. This is the wavelength. For example, the wavelength of a 60-Hz field is calculated as follows: 300,000,000 meters/second divided by 60 cycles/second 5,000,000 meters per cycle, 5,000 km or about 3,100 miles. The wavelength of a 2,450,000,000-Hz microwave in a microwave oven is about 0.12 meters (about 4.8 inches).

A crude rule of thumb is that the predominant electric and magnetic fields around an object exist independently at distances less than about one wavelength from the source. This is called the "near field." This is one reason why Table 1 is so important. The combination of electromagnetic radiation predominates at distances greater than about one wavelength. This is called the "far field."

Electric fields are measured in units of volts per meter (V/m). Magnetic fields are measured in units of amperes per meter (A/m), gauss (G), or tesla (T). So long as a magnetic field exists in something that is nonmagnetic, such as air and most biological tissue, gauss can be related directly to amperes per meter. One gauss is about 79.55 amperes per meter. One tesla is 10,000 gauss.

2.0 Hazards

Biological effects depend on the frequency and intensity of the electromagnetic radiation. Known biological hazards are

- Static magnetic fields (zero-Hz) with strengths of about 4 T can produce a variety of symptoms including nausea, metallic taste in the mouth, and vertigo.
- Electromagnetic fields can induce the current flow in the body. The threshold for perception and discomfort from such current flow is frequency dependent. At frequencies from 0 Hz to 100 MHz, a serious electrical shock can occur if the induced current flow in the body is great enough and there is a current path from the body to ground. This potential hazard can be assessed using a clamp-on meter available from the Hazards Control Department.
- Radio frequency and microwave energy can cause heating equivalent to that in a microwave oven. Heating becomes significant at frequencies in the MHz and GHz range, especially between about 30 and 300 MHz. Microwave energy is known to cause cataracts and skin burns in humans.

Static- and lower-frequency fields are known to induce malfunctions in medical electronic implants, such as pacemakers, which can malfunction at field strengths well below applicable occupational exposure limits. As a result, the only precautions needed where elevated static- and lower-frequency fields exist, in many cases, is to warn pacemaker users to stay out of the area and to keep tools and magnetizable objects out of places where elevated static magnetic fields are present.

Tools and compressed-gas cylinders can become uncontrollable and fly like missiles toward magnets in areas where there are strong static fields and strong field gradients (changes in field strength over distance). These same hazards also apply to people with metallic prosthetic implants (e.g., aneurysm clips, pins, or hip replacements). Therefore, the Health Services Department maintains a list of medical devices, implants, and special situations (such as wearing certain types of "metallic" make up) that are potentially hazardous in static magnetic fields. Mechanical hazards depend on the field strength and the field gradient, and also on how rapidly the magnetic field strength changes with distance. This means a field-strength measurement alone is not sufficient to adequately identify a hazardous situation. A supplemental survey method is described in the following text. Static fields also can be a nuisance because they can erase data stored on magnetic media or on the strips of credit/debit cards and badges.

Concerns have been expressed about a possible link between cancer and all forms of nonionizing radiation, especially cell phones and power lines (60 Hz). The issue has not been resolved and probably will remain an open issue for some time to come. The preponderance of available information suggests that power-line fields are either not related to causing cancer or, at worst, are a very mild hazard. Similarly, there are no replicated studies linking cell phones to causing cancer. The exposure criteria in this document are intended to prevent known or readily predictable effects, and are not based on the risk of cancer.

3.0 Operational and Administrative Controls

This section contains requirements for dc magnetic and electric fields; subradio-frequency fields, including 60 Hz; radio-frequency/microwave radiation and fields (rf/mw); and pulsed and intense fields.

Engineered controls (e.g., shielding and isolation) shall be used to restrict exposure whenever practical. Signs complying with good industrial practice, as specified in Document 12.1, "Access Control, Safety Signs, Safety Interlocks, and Alarm Systems," in the *ES&H Manual*, shall be posted conspicuously inside and at all entrances to areas described here.

3.1 Static Magnetic Fields (0 Hz)

The controls below apply to work areas where dc magnetic fields exist. These controls are based on exposure guidelines developed by the International Commission for Nonionizing Radiation Protection (ICNIRP) and which are summarized in Table A-1 of Appendix A.

- Only authorized personnel may be allowed into areas where high-intensity magnetic fields (HIMFs) exceed 100 mT (1000 G). Further, such authorized personnel shall be screened by the Health Services Department before beginning work that exposes them to magnetic fields.
- Magnetic fields can interfere with the body's sense of time when day and night cues are absent. Therefore, personnel should not work more than 12 hours per shift in areas where fields exceed 100 mT.
- Caution signs shall be posted in areas where magnetic field strengths could exceed 0.5 mT (5 G), warning people with pacemakers or other medical electronic implants to keep out of the area and warning individuals with magnetizable implants to check with management before entering the area.
- People with metallic medical implants shall be kept out of areas where field strengths exceed 3 mT (30 G).
- Areas where magnetic fields exceed 3 mT shall be surveyed to determine where potential mechanical hazards exist. A string of paper clips fastened to each other can be used to locate areas where strong attractive forces exist.
- Areas where potential mechanical hazards exist shall be conspicuously demarcated; and tools, compressed-gas cylinders, and other articles made of magnetically permeable material shall be kept out of such areas.
- Danger signs warning people about tool hazards shall be posted in areas where fields exceed 3 mT and in areas where there is a potential mechanical hazard. However, signs are not necessary if a survey finds that there are no mechanical hazards in areas where fields are greater than or equal to 3 mT. Danger signs that warn about tool hazards and the access limit for authorized personnel shall be posted in areas where fields exceed 2 T (20 kG). These signs shall also be posted where static magnetic fields exceed 4 T (40 kG), warning people to stay out of the area and of possible headaches.

3.2 Subradio-Frequency Fields (0–4000 Hz electric, >6–300 Hz magnetic, including 60 Hz)

The controls below apply to work areas where subradio-frequency fields exist. These controls are based on the Physical Agent Threshold Limit Values adopted in the Work Smart Standards set and guidelines developed by ICNIRP. These are summarized in Table A-1 of Appendix A.

- People with pacemakers shall be kept out of areas where 60-Hz electric fields exceed 1 kV/m, as demonstrated by measurement or calculation. Caution signs shall be posted at the entrances to these areas advising people with pacemakers

to keep out. However, signs are not necessary at every inventoried source, provided measurements or calculations ensure that the fields will not exceed 1 kV/m. Only authorized personnel may be allowed into these areas.

- Insulating garments and equipment should be used in areas where 60-Hz electric fields exceed 5 kV/m, as demonstrated by measurement or calculation. Insulating gloves or, preferably, engineered controls (e.g., enclosure or shielding of a field source) shall be used to avoid contact with objects that could expose personnel to sparks associated with field strengths greater than or equal to 5 kV/m. Caution signs shall be posted in the areas warning people that irritating sparks are possible. However, signs are not necessary at every inventoried source, provided measurements or calculations ensure that the fields will not exceed 5 kV/m.
- Insulating garments and equipment shall be used in areas where 60-Hz electric fields exceed 15 kV/m. Controls such as access limits and/or enclosures shall be considered. Warning signs shall be posted in these areas warning people that irritating sparks are possible.
- People with pacemakers shall be kept out of areas where 60-Hz magnetic fields exceed 0.1 mT (1 G), as demonstrated by measurement or calculation. Caution signs shall be posted at the entrances to these areas warning people with pacemakers to keep out. However, signs are not necessary at every inventoried source, provided measurements or calculations ensure that the fields will not exceed 0.1 mT.
- Areas where whole-body exposures to 60-Hz fields exceed 25 kV/m or 1 mT (10 G) shall be limited by positive means such as locked enclosures, interlocks, or safety chains (see Document 12.1). In addition, warning signs shall be posted in these areas. Exposures to 60-Hz magnetic fields are permissible up to 5 mT (50 G) in the arms and legs and up to 10 mT (100 G) in the hands and feet. Contact your ES&H Team for guidance about frequencies other than 60 Hz.

3.3 Radio-Frequency/Microwave Radiation and Fields (>4000 Hz electric, >300 Hz magnetic)

The controls below apply to work areas where radio-frequency/microwave radiation (rf/mw) and fields exist. These controls are based on IEEE C95.1-1991 adopted in the Work Smart Standards set.

- Working time limits based on the averaging intervals specified in IEEE C95.1-1991 shall be used when engineered controls are not practical. Note that proven personal protective equipment is not available.

- Signs warning of rf/mw hazards shall be posted on the access panels of irradiated enclosures of equipment and on both inside and at the entrances to areas where people could be exposed to radiation or field strengths above the limits specified in Tables A-2 through A-4 of Appendix A. Signs shall be used to post these areas in accordance with the guidance in Document 12.1 and as shown in Table A-5 of Appendix A. Caution signs shall be posted in these areas, unless exposure to continuous wave rf/mw exceeds 35 times the applicable power density or the square of the electric field-strength limits given in Table A-2. If magnetic fields exceed the field-strength limits given in Table A-2, warning signs shall be used.
- "High-hazard exclusion areas" are areas where exposure to continuous wave rf/mw exceeds 35 times the applicable power density (or the square of the electric field-strength limits) or where magnetic fields exceed the applicable field-strength limits given in Table A-2. Access to these areas shall be limited by positive means such as locked enclosures, interlocks, or safety chains. In addition, warning signs shall be used in the area as specified in Document 12.1.
- Caution signs shall be posted if radio-frequency current flows exceed the general public levels specified in Table A-3 of Appendix A. Warning signs shall be posted where the radio-frequency current flows could exceed the occupational exposure limits in Table A-2 of Appendix A. Narrative signs can be used; there is no suitable graphic for these signs. Controls such as access limits and/or enclosures shall be considered.
- Signs do not have to be posted on microwave ovens unless they are used intensively. In such cases, the sign shall be posted on or near the oven—not at the building entrance—and need only advise pacemaker users to keep out of the immediate area.

3.4 Pulsed and Intense Fields

The following controls are necessary for work areas where pulsed and intense fields exist:

- Only authorized personnel shall be allowed into areas where pulsed-peak rf/mw or field levels exceed the limit defined by the formula specified in IEEE C95.1-1991, where electric fields are greater than 100 kV/m, and where the rate at which whole-body magnetic fields change is greater than 5 T/s (50 kG/s) over the whole body. In addition, warning signs shall be posted in these areas.

- Work areas shall be regarded as high-hazard exclusion areas where
  - — Pulsed fields exceed 35 times the exposure limit using the following IEEE formula from IEEE C95.1-1991:

$$\frac{\text{cw limit} \times \text{averaging time (in seconds)}}{5 \times \text{pulse width (in seconds)}}$$

  - — Electric fields exceed 200 kV/m.
  - — The rate at which whole-body magnetic fields change strength exceeds 35 T/s (350 kG/s).

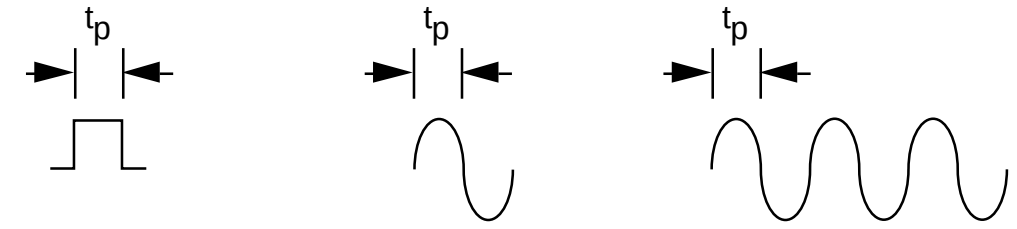
Exposure to pulsed rf/mw shall be limited so that the ambient electric field strength does not exceed 100 kV/m. The peak exposure shall not exceed the following:

- In accordance with the IEEE/ANSI C95.1-1991 standard, the cw limits and averaging times given in Tables A-2 and A-3 of Appendix A apply to situations where there are more than five pulses during the averaging time.
- In accordance with *Exposure Standard for Pulsed Magnetic Fields* (UCRL-AR-133353), peak magnetic fields shall not exceed the limits in Fig.1.

Note that the following waveforms are used to determine the rate of change of the pulsed magnetic field:

- For square waveforms, duration = t_p
- For single sinusoidal waveform pulses, duration = duration of half cycle
- For pulse containing multiple sine waves, frequency = duration of a half cycle of the sine waves.

These relationships are depicted as follows:



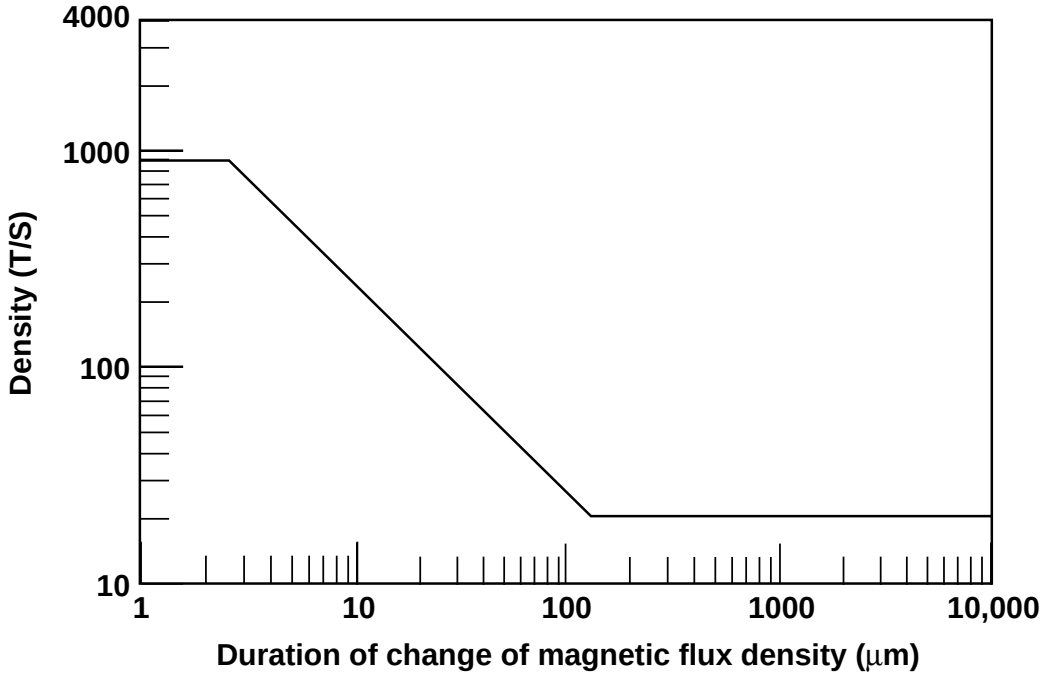


Figure 1. Permissible rates of change of a pulsed magnetic field.

3.5 Postings and Surveys

Document 10.2 states that the Hazard Notice Door Sign shall be used as a minimum to identify potentially hazardous physical agents. When a physical agent hazard is identified on the sign, the area ES&H Team will evaluate the hazard. This evaluation may be used as part of the area-specific hazard communication plan. This section gives guidance on nonionizing radiation sources that must be identified on the Hazard Notice Door Sign.

Access to areas where nonionizing radiation sources are present shall be limited by positive means such as locked enclosures, interlocks, or safety chains as specified in Document 12.1. In addition, danger signs shall be posted in these areas.

3.5.1 Postings

The following equipment shall be identified on the area Hazard Notice Door Sign:

- Steady (dc) magnets that could generate fields above 0.5 mT (5 G) to the chest under normal-use conditions. Common horseshoe and bar magnets do not need to be inventoried but, for example, Faraday rotators with permanent magnets or other larger permanent magnets shall be inventoried. It is noted that a small percentage of pacemakers could malfunction in fields weaker than 0.5 mT; the most sensitive known pacemaker could malfunction in a 0.31-mT (3.1 G) field.

- Equipment that could create 60-Hz electric fields above 2.5 kV/m or magnetic fields above 0.1 mT (1 G). For electric fields, this is equipment that operates above 2.5 kV without electric-field shielding between the source and people; for magnetic fields, it is equipment that operates above 100 A. Some cardiac pacemakers can malfunction if subjected to 60-Hz field strengths above 0.1 mT or 1 kV/m.
- All permanently installed rf gear capable of radiating over 1 W into an open area at frequencies between 3 kHz and 300 GHz or of emitting over 100 W if the output is normally completely enclosed by coaxial cables, waveguides, or dummy or real loads.
- All satellites and permanently installed communications transmitters. (Receivers do not have to be listed.)
- Portable walkie-talkie communication sets capable of radiating over 7 W at frequencies between 100 kHz and 450 MHz, and over $7(450/f_m)$ W at frequencies between 450 MHz and 1.5 GHz (f_m = frequency in MHz units).
- All induction heaters.
- Main power-supply rooms of buildings.

Exemption from the Posting Requirement. Microwave ovens, household appliances (e.g., refrigerators and conventional ovens), cellular phones, and video display terminals (VDTs) do not have to be listed on the Hazard Notice Door Sign. Likewise, storage locations do not have to be listed if the equipment is stored such that it cannot emit energy. For example, rf emitters would not be inventoried at storage locations. However, when in doubt, the equipment should be listed.

3.5.2 Surveys

Equipment in inventory that has the potential to generate excessive exposure to fields shall be evaluated, except for the following:

- Walkie-talkies.
- Electronic test apparatus. (Exposure to representative gear shall be evaluated, but the equipment user and the Hazards Control Department shall both agree about the equipment to be the evaluated.)
- Other classes of equipment. The Hazards Control Department will determine which classes of equipment will be exempt from evaluation based on experience.

Whenever possible, evaluations will be made by exposure measurements when the equipment is first set up and after significant modifications. Equipment that is already set up, but not yet evaluated, shall be evaluated as new equipment. The selection of appropriate measurement instruments depends on the frequency of the electromagnetic radiation.

3.6 Training

Anyone who may be reasonably expected to be exposed to fields or radiation emitted by the equipment listed in Section 3.5.1 shall take Course HS4730. This Web-based course covers the health effects of rf/mw radiation and fields and dc magnetic fields. Some basic concepts of the physical properties are given as background for a discussion on exposure standards and control measures. More detailed information can be found at the following Internet address:

http://www-training.llnl.gov/training/hc/NonIonizing/NonIonizing.html

Information about the specific hazards of equipment shall be provided as part of the familiarization process for new employees. Workers shall be made aware of the safety characteristics of the equipment they use such as frequency, pulsed or continuous wave mode of operation, pulse duration and repetition rate (when applicable), and output power as well as the safety guidance provided by equipment manufacturers.

3.7 Exposure Limits

Experimenters, workers, and working visitors are covered by the controlled access/occupational exposure criteria specified Tables A-1, A-3, and A-4 in Appendix A. Fetuses, minors, and nonworking visitors are covered by the uncontrolled access/general-public exposure criteria specified in Table A-3 of Appendix A.

4.0 Responsibilities

This section describes the responsibilities of personnel who work in areas where exposure to radiation and fields covered in this document is possible. General responsibilities for all workers are described in Document 2.1,"Laboratory and ES&H Policies, General Worker Responsibilities, and Integrated Safety Management," in the *ES&H Manual.*

4.1 Workers

- Direct questions or concerns about nonionizing radiation/fields to your work supervisor for resolution.

- Comply with the safety controls associated with your work assignment such that found in Safety Plans, instructions issued by your supervisor, or safety guidance provided in manufacturers' instructions.
- Complete training as required for your job assignment.

4.2 Responsible Individuals

- Maintain awareness of the output and safety characteristics of the equipment such as frequency, pulsed or continuous wave mode of operation, pulse duration and repetition rate (when applicable), and output power as well as the safety guidance provided by equipment manufacturers.
- Ensure that workers are properly trained in the hazards and controls for the work assigned.
- Ensure that workers comply with safety requirements.
- Before purchasing or fabricating any equipment that generates nonionizing radiation or fields of the types listed in Section 3.5.1, discuss the planned use of such equipment with the area ES&H Team.
- Ensure that workers are not exposed to fields or radiation above the levels specified in this document.
- Identify sources listed in Section 3.5.1 on the Hazard Notice Door Sign.
- Evaluate exposures to nonionizing radiation and fields arising from equipment to be inventoried. Call your ES&H Team to make arrangements for this evaluation.
- Provide the Health Services Department with all relevant information regarding workers' work environment and activities. Contact the Health Services Department for guidance.
- Ensure workers contact the Health Services Department prior to beginning work in areas where magnetic fields (as described in Sections 3.1 and 3.2) could create potential hazards.

4.3 Hazards Control Department

4.3.1 ES&H Teams

- Regularly check the Hazard Notice Door Signs that indicate the presence of nonionizing radiation sources in an area.

- Assist area supervisors and individuals planning to procure or use nonionizing radiation and fields with evaluations, and provide guidance on controlling exposures to these sources.
- Advise the Health Services Department when worker exposures to static magnetic fields exceed the definition given in Section 3.1 for HIMFs, or where workers are exposed to subradio-frequency and radio-frequency fields or radiation above the occupational exposure criteria listed in Tables A-1, A-2, and A-4 in Appendix A.

4.3.2 Nonionizing Radiation Safety Officer

- Support ES&H Team health physicists and industrial hygienists, as requested, when they provide guidance to work supervisors and workers or survey radiation and field sources.
- Provide technical support and develop policy guidance for the safe use of nonionizing radiation.
- Prepare and revise training materials.
- Revise this document for approval by the ES&H Working Group.

4.3.3 Safety, Education, and Training Section

The Safety, Education and Training Section shall provide training in the HS437X series to individuals who use the equipment listed in Section 3.5.1.

4.4 Health Services Department

A pre-placement examination is required for employment at LLNL to determine a worker's physical capabilities in relation to the prospective job. In addition, the Health Services Department will review all job transfers to determine if further medical evaluation is necessary prior to the worker beginning work.

All individuals with potential occupational exposure to HIMFs, as defined in Section 3.1 and 3.2, must complete a magnetic field questionnaire and have it reviewed by the Health Services Department prior to beginning work in an HIMF area. Individuals identified by the Hazards Control Department as having potential exposures to HIMF above 100 mT (1000 G) must be screened by the Health Services Department.

5.0 Work Smart Standards

International Commission on Non-Ionizing Radiation Protection. "Guidelines on Limits of Exposure to Static Magnetic Fields," *Health Phys*. **66**, 100–106 (1994).

ACGIH TLVs and BEIs, *Threshold Limit Values for Chemical Substances and Physical Agents in the Work Environment*. ACGIH, Cincinnati, OH (1998).

Institute of Electrical and Electronic Engineers, *American National Standard Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to* 300 GHz, IEEE, Piscataway, NJ, C95.1-1991 (1992).

Miller, G. C., *Exposure Standard for Pulsed Magnetic Fields*, UCRL-AR-133353. Lawrence Livermore National Laboratory (1999).

The following document is not included in the Work Smart Standard set, but is the best available guidance for dealing with public exposures to power line fields:

International Nonionizing Radiation Committee of the International Radiation Protection Association. "Interim Guidelines on Limits of Exposure to 50/60 Hz Electric and Magnetic Fields," *Health Phys*. **58**, 113–122 (1990).

6.0 Resources for More Information

6.1 Contacts

Contact the area ES&H Team for more information about access nonionizing radiation and fields.

6.2 Lessons Learned

For lessons learned applicable to the topics discussed in this document, refer to the following Internet address:

http://www-r.llnl.gov/es_and_h/lessons/lessons.shtml

6.3 Other Sources

The following document is for public health and ES&H personnel and should be read by Hazards Control Department managers and staff encountering nonionizing radiation issues:

G. C. Miller. "Nonionizing Radiation", Chapter 11 of *Fundamentals of Industrial Hygiene*, 4th ed., B. Plog, J. Niland, and P. Quinlan, eds. National Safety Council, Itasca, IL (1996).

The following documents are for public health and ES&H personnel and should be read by Hazards Control Department disciplines encountering nonionizing radiation issues:

R. T. Hitchcock, Radio-Frequency and Microwave radiation - Nonionizing radiation Guide Series. American Industrial Hygiene Association, Fairfax, VA (1994).

R. T. Hitchcock, S. McMahan, and G. C. Miller, Extremely Low Frequency (ELF) Electric and Magnetic Fields - Nonionizing radiation Guide Series. American Industrial Hygiene Association, Fairfax, VA (1995).

R. T. Hitchcock et al., "Nonionizing Radiation", Chapter 21 of *The Occupational Environment, Its Evaluation and Control*, S. diNardi ed. American Industrial Hygiene Association, Fairfax, VA (1997).

G. C. Miller, "Exposure Guidelines for Magnetic Fields," *J. American Industrial Hygiene Association*, **48,** 957–968 (1987).

The following documents are for all interested readers:

A. Leonard, R. Neutra, M. Yost and G. Lee, Electric and Magnetic Fields: Measurements and Possible Effects on Human Health from Appliances, Power Lines and Other Common Sources—What We Know and What We Don't Know in 1990, Special Epidemiological Studies Program, California Department of Health Services, Berkeley, CA (1990).

I. Nair, M. G. Morgan and H. K. Florig, *Biological Effects of Power Frequency Electric and Magnetic Fields*, U. S. Government Printing Office, Washington, DC, OTA-BP-E-53 (1989).

C. J. Portier and M. S. Wolfe, eds. *Assessment of Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields—Working Group Report*, NIH Publication No. 98-3981. National Institute of Environmental Health Sciences, Research Triangle Park, NC (1998). It was hoped that the project, which this report effectively closed out, would resolve the power line and cancer issue. This did not happen and the issue remains open with essentially no prospect of closure. It is a long document and a scientific background is helpful for understanding it.

Reilly, J. Patrick, "Maximum Electromagnetic Field Limits Based on Peripheral Nerve Stimulation: Application to IEEE/ANSI C95.1 Electromagnetic Field Standards," *IEEE Transactions on Biomedical Engineering*, 45 (1): 137-141 (1998).

Appendix A

Exposure Criteria

The five tables in this appendix give exposure criteria for ac and dc magnetic fields. There are no Occupational Safety and Health Administration (OSHA) regulations for any of the fields or radiation covered in this document. The 1974 Noblecraft decision by the Occupational Safety and Health Review Commission voided OSHA's original nonionizing radiation standard. However, the 1987 *United Auto Workers (UAW) and Brock vs General Dynamics Land Systems Division* decisions allowed OSHA to enforce consensus standards through the General Duty Clause of the Act when there is no standard for a specific hazard.

Table A-1. Exposure guidelines for dc and ac fields below 3 kHz.[a]

				Permissible exposure		
Frequency	Exposure group	Exposure duration	Exposed part of body	Electric (kV/m)	Magnetic (mT)[b]	Reference[c]
dc	Occupational	Shift	All	—	200	ICNIRP 1994
dc	Occupational	Ceiling	All	—	2000	"
dc	Occupational	Ceiling	Limbs	—	5000	"
dc	Public	24 hr/day	All	—	40[g]	ICNIRP 1990
50/60 Hz	Public	24 hr/day	All	5	0.1	"
50/60 Hz	Public	"Few hrs/day"[d]	All	10	1	"
1 Hz–294 Hz	Occupational	Ceiling[e]	All	—	60/f[f]	TLV
1 Hz–294 Hz	Occupational	Ceiling[e]	Limbs	—	300/f[f]	"
dc–4.071 kHz	Occupational	Ceiling[e]	All	25	—	"
100 Hz–4.071 kHz	Occupational	Ceiling[e]	All	2500/f[f]	—	"
100 Hz–4.071 kHz	Occupational	Ceiling[e]	All	2500/f[f]	—	"

[a] See International Commission Non-Ionizing Radiation Protection "Guidelines on Limits of Exposure to Static Magnetic Diode," Health Phys. 66, 100–106 (1994).

ACGIH TLVs and BEIs. Threshold Limit Values for Chemical Substances in the Work Environment, ACGIH, Cincinnati, OH (1998).

International Nonionizing Radiation Committee of the International Radiation Protection Association, "International Guidelines on Limited Exposure to 160 Hz Electrical Magnetic Fields," Health Phys. 58, 113–122 (1990).

[b] 1 mT = 10 G = 796 (~800 A/m).

[c] ICNIRP 1994 is International Commission on Non-Ionizing Radiation Protection. "Guidelines on Limits of Exposure to Static Magnetic Fields," Health Phys. 66, 100–106 (1994). ICNIRP 1990 is International Nonionizing Radiation Committee of the International Radiation Protection Association (now the International Commission on Non-Ionizing Radiation Protection). "Interim Guidelines on Limits of Exposure to 50/60 Hz Electric and Magnetic Fields," Health Phys. 58, 113–122 (1990). TLV is American Conference of Governmental Industrial Hygienists, Threshold Limit Values for Physical Agents in the Work Environment. ACGIH, Cincinnati, OH (latest edition).

[d] Exposures to electric fields between 5 and 10 kV/m or magnetic fields between 0.1 and 1 mT should be limited to a few hr/day, continuous exposures to electric fields >5 kV/m or magnetic fields >1 mT should not be allowed, and exposures to electric fields >10 kV/m or magnetic fields >1 mT should be limited to a few min/day (electric field exposures >10 kV/m is allowed if induced current density is <2 mA/m2).

[e] Maximum exposure allowed at any time.

[f] Frequency in units of Hz.

[g] Exposures to higher fields in special facilities is allowed if access controlled and occupational exposure limits are not exceeded.

Table A-2. Controlled access exposure limits (from IEEE C95.1-1991).

Part A—Electromagnetic fields[a]				
Frequency range (MHz)	**E (V/m) [b]**	**H (A/m) [b, d]**	**Power density, S [E, H] (mW/cm^2)**	**Averaging time E^2, H^2, or S (min)**
0.000294–0.1	—	163	[100, 1 000 000][c]	6
0.00407–0.1	614	—	[100, 1 000 000][c]	6
0.1–3	614	$16.3 / f_m$	[100, $10\,000/f_m^2$][c]	6
3–30	$1842/f_m$	$16.3/f_m$	[$900/f_m^2$, $10\,000/f_m^2$][c]	6
30–100	61.4	$16.3/f_m$	[1.0, $10\,000/f_m^2$][c]	6
100–300	61.4	0.163	1.0	6
300–3000	—	—	$f_m/300$	6
3000–15 000	—	—	10	6
15 000–300 000	—	—	10	$616\,000/f_m^{1.2}$

Part B—Induced and contact radio-frequency currents			
Frequency range (MHz)	**Through both feet**	**Maximum current (mA) Through each foot**	**Contact**
0.003–0.1	$2000\ f_m$	$1000\ f_m$	$1000\ f_m$
0.1–100	200	100	100

Note: f_m = frequency in units of MHz.

a The exposure values in terms of electric and magnetic field strength are the values obtained by spatially averaging values over an area equivalent to the vertical cross section of the human body (projected area).

b Higher exposures are allowed in the extremities as specified in Table A-4.

c These plane-wave-equivalent, power-density values, although not appropriate for near-field conditions, are commonly used as a convenient comparison with MPEs at higher frequencies and are displayed on some instruments in use.

d A/m = Amp-turn/meter.

Table A-3. Uncontrolled access exposure limits (from IEEE C95.1-1991).

Part A—Electromagnetic fields[a]					
			Power density, S	Averaging time	
Frequency range (MHz)	E (V/m) [b]	H (A/m)[b, c]	[E, H] (mW/cm^2)	E^2 and S (min)	H^2 (min)
0.003–0.1	614	163	[100, 1 000 000][d]	6	6
0.1–1.34	614	$16.3/f_m$	[100, $10\,000/f_m^2$][d]	6	6
1.34–3	$823.8/f_m$	$16.3/f_m$	[$180/f_m^2$, $10\,000/f_m^2$][d]	$f_m^2/0.3$	6
3–30	$823.8/f_m$	$16.3/f_m$	[$180/f_m^2$, $10\,000/f_m^2$][d]	30	6
30–100	27.5	$158.3/f_m^{1.668}$	[0.2, $940\,000/f_m^{3.336}$][d]	30	$0.0636f_m^{1.337}$
100–300	27.5	0.0729	0.2	30	30
300–3000	—	—	$f_m/1500$	30	—
3–15 000	—	—	$f_m/1500$	$90\,000/f_m$	—
15 000–300 000	—	—	10	$616\,000/f_m^{1.2}$	—

Part B—Induced and contact radio-frequency currents			
Frequency range (Hz)	Maximum current (mA)		
	Through both feet	Through each foot	Contact
0.003–0.1	$900f_m$	$450f_m$	$450f_m$
0.1–100	90	45	45

Note: f_m = frequency in units of MHz.

[a] The exposure values in terms of electric and magnetic field strength are the values obtained by spatially averaging values over an area equivalent to the vertical cross section of the human body (projected area).

[b] Higher exposures are allowed in the extremities as specified in Table A-4.

[c] A/m = Amp-turn/meter.

[d] These plane-wave-equivalent, power-density values, although not appropriate for near-field conditions, are commonly used as a convenient comparison with MPEs at higher frequency and are displayed on some instruments in use.

Table A-4. Relaxation values for partial body exposures (from IEEE C95.1-1991) [a].

	Frequency (MHz)	Peak value of mean-squared fields	Equivalent power density (mW/cm^2)
Occupational exposures	$0.1 \le f_m < 300$	$<20E'^2$ or $20H'^2$ [b]	—
	$300 < f_m \le 6000$	—	<20
	$6000 < f_m \le 96\,000$	—	$<20\ (1000\ f_m/6)^{1/4}$
	$96\,000 < f_m \le 300\,000$	—	40
Public exposures	$0.1 \le f_m < 300$	$<20E'^2$ or $20H'^2$ [c]	—
	$300 < f_m \le 6000$	—	<20
	$6000 < f_m \le 96\,000$	—	$1000\ f_m/1.5$
	$96\,000 < f_m \le 300\,000$	—	20

Note: f_m = frequency in MHz.

[a] These relaxation values do not apply to the eyes and testes.

[b] E' and H' are the spatially averaged values from Table A-2.

[c] E' and H' are the spatially averaged values from Table A-3.

Table A-5. Warning signs to be posted where potential nonionizing radiation hazards exist.[a,b]

Frequency	Field	Situation	Signal Word	Symbol	Typical Legend[c]
Static	Electric	Field greater than 5 kV/m	CAUTION		Strong electric field. Irritating sparks possible Use insulating garments/equipment Authorized personnel only
"	"	Field greater than 15 kV/m	WARNING		As above
"	Magnetic	Field greater than 0.5 mT (5 G)	CAUTION		Strong magnetic field People with pacemakers and medical. electronic implants must stay out! Damage to watches, instruments & magnetic media possible
"	"	Field greater than 3 mT (30 G) AND survey shows potential mechanical hazards exist	DANGER		Keep magnetizable tools and objects out of the area! Keep people with medical implants out of area, unless approved by Health Services and Hazards Control
"	"	Field greater than 2 T (20 kG)	DANGER		Keep magnetizable tools and objects out of the area! Keep people with medical implants out of area, unless approved by Health Services and Hazards Control Intense magnetic field Authorized personnel only

Table A-5. Warning signs to be posted where potential nonionizing radiation hazards exist.[a,b] (cont'd)

Frequency	Field	Situation	Signal Word	Symbol	Typical Legend[c]
Static (cont'd)	Magnetic (cont'd)	Field greater than 4 T (40 kG)	DANGER		Keep out! Headaches possible Keep magnetizable tools and objects out of area! Keep people with medical implants out of the area, unless approved by Health Services and Hazards Control Extremely intense magnetic field
Greater than static–3 kHz	Electric	Field greater than the 1/25 limits specified in Table A-1 (1 kV/m at 60 Hz)	CAUTION	 [d]	Strong electric field Pacemaker users keep out Authorized personnel only
"	"	Field greater than 5 kV/m	CAUTION	 [d]	Strong electric field. Irritating sparks possible Use insulating garment/equipment Pacemaker users keep out Authorized personnel only
"	"	Field greater than 15 kV/m	WARNING	 [d]	"
"	"	Field greater than 25 kV/m	WARNING	 [d]	Keep out! Strong electric field Irritating sparks possible Use insulating garment/equipment. Pacemaker users keep out

Table A-5. Warning signs to be posted where potential nonionizing radiation hazards exist.[a,b] (cont'd)

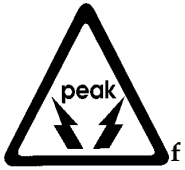
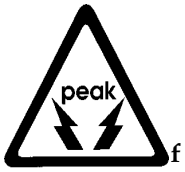
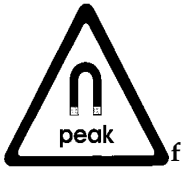
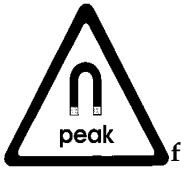
Frequency	Field	Situation	Signal Word	Symbol	Typical Legend.[c]
Greater than static–3 kHz (cont'd)	Magnetic	Field greater than one-tenth the limits specified in Table A-1 (1 G at 60 Hz)		 [d]	Strong magnetic field. Pacemaker users keep out
"	Magnetic	Whole-body average field greater than the limits specified in Table A-1	WARNING	 [d]	Strong magnetic field Pacemaker users keep out Keep out!
3 kHz–300 GHz	Electric, magnetic, or radiation	Levels greater than the controlled access criteria given in Table A-2, but less than 35 times the levels specified in Table A-2	CAUTION		Radio-frequency[e] radiation hazard Authorized personnel only.
3 kHz–300 GHz	Electric, magnetic, or radiation	Levels greater than or equal to 35 times the levels specified in Table A-2	DANGER		Radio-frequency[e] radiation hazard Keep out!
Any combination	Electric	Peak field greater than 100 kV/m	WARNING	 [f]	Intense electric field Overexposure possible Precautions required Authorized personnel only
"	"	Field greater than 200 kV/m	DANGER	 [f]	Very intense electric field Keep out!

Table A-5. Warning signs to be posted where potential nonionizing radiation hazards exist.[a,b] (cont'd)

Frequency	Field	Situation	Signal Word	Symbol	Typical Legend.[c]
Any combination (cont'd)	Magnetic	Field rate of change greater than 5 mT/s (50 G/s)		 [f]	Intense magnetic field Overexposure possible Precautions required Authorized personnel only
"	"	Field rate of change greater than 35 mT/s (350 G/s)	DANGER	 [f]	Very intense magnetic field Keep out!
3 kHz–300 GHz	Electric, magnetic, or radiation	Peak field greater than the level calculated using the formula in Section 4.4 of this document, but is less than 35 times that value	WARNING	 [f]	Intense pulsed radio-frequency[e] radiation Overexposure possible Precautions required Authorized personnel only
"	"	Peak field greater than 35 times the level calculated using the formula in Section 4.4 of this document	DANGER	 [f]	Very intense pulsed radio-frequency[c] radiation Keep out!

[a] Layout of signs to comply with guidance of Document 12.1.

[b] Signs prepared in accordance with editions of Document 20.7 issued on or after November 1995 can still be posted.

[c] Typical legend is shown. The message should be tailored to meet local meets. For example, a generic warning can be posted at entranceways to a lab or area containing equipment that generates potentially hazardous fields in small areas. The room entrance signs would warn people to check with the responsible person and state what the hazard and equipment were. Then the equipment would also be labeled to warn people to stay some distance away from it.

[d] Other frequencies between dc and 3 kHz or the words "pulse", pulsed", or "peak" can be entered where "60 Hz" appears. Contact your ES&H field team for guidance on subradio frequencies other than 60 Hz.

[e] The words "microwave" or "radio frequency/microwave" can be substituted for the word "radio frequency."

[f] The words "pulse" or "pulsed" can be substituted for the word "peak."