TEMPORARY CHANGE REQUEST

TCR NO. TCR-ESHD-5008-Sect 04, R5-001

The Temporary Change Request (TCR) Form is to be used to process urgent or minor changes for PPPL Policies, Organization/Mission Statements and Procedures. The TCR should be used when changes are:
1) urgent, and can not wait the 2-4 week period for Department Head review/comment, or
2) minor, and do not warrant Department Head review. **Person Requesting Change: William Slavin**

Department Name: ES&H/Infrastructure Support **Phone Ext: 2533**

Document Number: ESHD 5008, Section 4 **Revision No.: 5**

Document Title: RF, Microwave and Magnetic Field Safety

Reason for change: To change the requirement from a RF Technician Qualification to allowing trained RF Surveyor to perform leakage surveys.

Change description: (Summarize and attach changed pages, with changes clearly indicated)

ES&HD 5008, Section 4, Item 4.4.6 will be changed to read,

4.4.6 The RF Engineering Group is responsible for:

A. Developing and maintaining an RF Surveyor Training Standard to ensure proper training for personnel performing RF leakage surveys. This training shall include at a minimum:

1. Definitions and hazards pertaining to RF radiation
2. Locations of possible RF emanations for sources to be surveyed
3. Proper use of RF monitoring equipment
4. Proper controls for safe access to RF generating equipment.

B. Training RF Surveyors to perform RF leakage surveys.

C. Performing leakage surveys of all RF equipment at least annually and after extensive modifications to systems. This activity may be delegated to other Trained RF Surveyors outside the Group as appropriate.

D. Providing copies of all RF leakage survey results to Industrial Hygiene.

E. Training and/or Qualifying, as necessary, RF Technicians to safely perform work on RF equipment. This training will at a minimum include all items in paragraph 4.4.6.A above.

1. Does this TCR significantly alter the intent or scope of the document? **YES:**_____ **NO: X**
2. Does this TCR significantly impact **ES&H**? **YES:**_____ **NO: X**

If 1 or 2 is **YES**, Explain why the changes should not be routed for Department Head review:

_____

Jerry Levine **4/15/04**
Department/Division Head Approval **Date**

J. W. Anderson **4/15/04**
Head, ES&H and Infrastructure Support/designee **Date**

Release/Effective date of this TCR: **4/19/04**

Incorporate this TCR into next revision of this document? **Yes** X **No**_____

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SECTION 4: RF, MICROWAVE AND MAGNETIC FIELD SAFETY

4.1 INTRODUCTION

Static magnetic fields, microwave, and other radio-frequency radiations are produced by a wide variety of industrial, scientific, home appliance, and communication equipment. At sufficiently high intensities, exposure to static, RF, and microwave electromagnetic fields can produce a variety of adverse health effects. Such effects include cataracts of the eye, overloading of the thermoregulatory response, thermal injury, altered behavioral patterns, convulsions, and decreased endurance. It is the purpose of this section to provide safety guidelines to minimize the potential hazards to health that radio frequency, microwave, and static-magnetic field generating equipment present to PPPL employees and visitors. It is not intended to include infrared, visible, ultraviolet, ionizing radiation, or frequencies below 3000 Hz. Exposure criteria at PPPL follow the guidelines of DOE and the Institute of Electrical and Electronic Engineers (IEEE) C95.1-1999. The IEEE standard follows an exposure level that varies with the frequency of the radiation. For both pulsed and non-pulsed fields, the power density, the square of the field strengths, and the value of the specific absorption rates (SARs), or input power, are averaged over any 0.1 hour period (6 minutes). The time-averaged values should not exceed the values given in Tables 2 and 3 or Exclusions 4.5.6.

The present standard includes a distinction between controlled and uncontrolled environments and guidelines for partial-body and near-field exposures. Exposure limits in the uncontrolled environment are lower than in a controlled environment under certain conditions, such as resonance, or when exposure is complicated by associated hazards like RF shock or burn.

4.2 SCOPE AND PURPOSE

The intent of this section is to prevent harmful effects in human beings exposed to electromagnetic fields, to static magnetic fields using guidance given for the frequency range from 3 kHz to 300 GHz. These recommendations are intended to apply to exposures in controlled, as well as uncontrolled, environments. These recommendations are not intended to apply to the purposeful exposure of patients by or under the direction of practitioners of the healing arts in which, of course, PPPL does not engage. The recommendations at 300 GHz are compatible with existing recommendations on safe exposure in the infrared frequency range (starting at 300 GHz).

4.3 DEFINITIONS AND GLOSSARY OF TERMS

Average (temporal) Power (P_{avg}) - The time-averaged rate of energy transfer.

$$P_{avg} = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} P(t)\,dt$$

where

P(t) is the instantaneous power,
t_1 is the initial time,
t_2 is the final time of the interval over which P(t) is averaged.

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Averaging Time (T_{avg}) - The appropriate time period over which exposure is averaged for purposes of determining compliance with a Maximum Permissible Exposure (MPE). For exposure durations less than the averaging time, the maximum exposure, MPE', in any time interval equal to the averaging time is found from

$$MPE' = MPE\left(\frac{T_{avg}}{T_{exp}}\right)$$

where
T_{exp} is the exposure duration in that interval expressed in the same units as T_{avg}. (Restrictions on peak power density limit T_{exp}.)

Continuous Exposure - Exposure for durations exceeding the corresponding averaging time. Exposure for less than the averaging time is called *short-term exposure*.

Controlled Environment - Location where there is exposure that may be incurred by persons who are aware of the potential for exposure as a concomitant of employment, by other cognizant persons, or as the incidental result of transient passage through areas where analysis shows the exposure levels may be above those shown in Table 3 but do not exceed those in Table 2.

Duty Factor - The ratio of pulse duration to the pulse period of a periodic pulse train. A duty factor of 1.0 corresponds to continuous-wave (CW) operation.

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.

$$E = \frac{F}{q}$$

Electric field strength is expressed in units of volts per meter (V/m).

Energy Density (Electromagnetic Field) - The electromagnetic field energy contained in an infinitesimal volume divided by that volume.

Exposure - Exposure occurs whenever and wherever a person is subjected to electric, magnetic, or electromagnetic fields or to contact currents other than those originating from physiological processes in the body and other natural phenomena.

Exposure, partial-body - Exposure that results when RF fields are substantially non-uniform over the body. Fields that are non-uniform over volumes comparable to the human body may occur due to highly directional sources, standing-waves, re-radiating sources, or in the near field region of a radiating structure. See *RF "hot spot."*

Far-Field Region - That region of the field of an antenna where the angular field distribution is essentially independent of the distance from the antenna. In this region (also called the free-space region), the field has a predominantly plane-wave character, i.e., locally uniform distributions of electric-field strength and magnetic field strength in planes transverse to the direction of propagation.

Gauss (G) -. The CGS-electromagnetic unit of magnetic flux density. One Gauss (G) = 10-4 tesla.

Hertz (Hz) - The unit for expressing frequency, *f*. One hertz equals one cycle per second.

Magnetic Field Strength (H) - A field 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).

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Magnetic Flux Density (B) - A field vector quantity that results in a force (*F*) that acts on a moving charge or charges. The vector product of the velocity (*v*) at which an infinitesimal unit test charge, *q*, is moving with *B*, and is the force that acts on the test charge divided by *q*.

$$\frac{\boldsymbol{F}}{q} = (\boldsymbol{v} \times \boldsymbol{B})$$

Magnetic flux density is expressed in units of tesla (T). One T is equal to 10^4 gauss (G).

Maximum Permissible Exposure (MPE) - The root-mean squared (rms) and 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 to which a person may be exposed without harmful effect and with an acceptable safety factor.

Mixed Frequency Fields - The superposition of two or more electromagnetic fields of differing frequency.

Near-Field Region - A region generally in proximity to an antenna or other radiating structure, in which the electric and magnetic fields do not have a substantially plane-wave character, but vary considerably from point to point. The near-field region is further subdivided into the reactive near-field region, which is closest to the radiating structure and contains most or nearly all of the stored energy, and the radiating near-field region where the radiation field predominates over the reactive field, but lacks substantial plane-wave character and is complicated in structure.

NOTE: For most antennas, the outer boundary of the reactive near-field region is commonly taken to exist at a distance of one-half wavelength from the antenna surface.

Penetration Depth - For a plane electromagnetic wave incident on the boundary of a medium, the distance from the boundary into the medium along the direction of propagation in the medium, at which the field strengths of the wave have been reduced to 1/e (~36.8%) of the boundary values.

Power Density, Average (temporal) - The instantaneous power density integrated over a source repetition period.

Power Density (*S*) - Power per unit area normal to the direction of propagation, usually expressed in units of watts per square meter (W/m^2), or for convenience, in units such as milliwatts per square centimeter (mW/cm^2) or microwatts per square centimeter ($\mu W/cm^2$). For plane waves, power density, electric-field strength (*E*) and magnetic-field strength (*H*) are related by the impedance of free space, i.e., 377 ohms. In particular,

$$S = \frac{E^2}{377} = 377H^2$$

where E and H are expressed in units of V/m and A/m, respectively, and S in units of W/m^2. Although many survey instruments indicate power density units, the actual quantities measured are E or E^2, or H or H^2.

Power Density, Peak - The maximum instantaneous power density occurring when power is transmitted.

Power Density, plane-wave equivalent - A commonly used term associated with any electromagnetic wave, equal in magnitude to the power density of a plane wave having the same electric (E) or magnetic (H) field strength.

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Pulse Modulated Field - An electromagnetic field produced by the amplitude modulation of a continuous wave carrier by one or more pulses.

Radio Frequency (RF) – Non-ionizing, electromagnetic energy characterized by relatively long wavelength, low frequency, and low photon energy. Although the RF spectrum is formally defined in terms of frequency as extending from 0 to 3000 GHz, for purposes of this section, the frequency range of interest is 3 kHz to 300 GHz with microwave range from 300 MHz to 300 GHz.

Region	Frequency	Wavelength	Photon Energy
Microwave	300 GHz – 300 MHz	1 mm – 1 m	1.24 meV – 1.24 μeV
Radiowave	300 MHz – 3 kHz	1 m – 100 km	1.24 μeV – 0.01 neV

Note: RF is considered non-ionizing radiation because the photon energies are well below the 10 to 12 eV necessary to ionize water molecules.

Re-radiated Field - An electromagnetic field resulting from currents induced in a secondary, predominately conducting, object by electromagnetic waves incident on that object from one or more primary radiating structures or antennas. Re-radiated fields are sometimes called "reflected," or more correctly, "scattered fields." The scattering object is sometimes called a "re-radiator" or "secondary radiator" (see *scattered radiation*).

RF "Hot Spot" - A highly localized area of relatively more intense radio-frequency radiation that manifests itself in two principal ways:

1. The presence of intense electric or magnetic fields immediately adjacent to conductive objects that are immersed in lower-intensity ambient fields (often referred to as re-radiation).

2. Localized areas, not necessarily immediately close to conductive objects, where there exists a concentration of radio-frequency fields caused by reflections and/or narrow beams produced by high-gain radiating antennas or other highly directional sources.

In both cases, the fields are characterized by very rapid changes in field strength with distance. RF hot spots are normally associated with very non-uniform exposure of the body (partial-body exposure). This is *not* to be confused with an actual thermal hot spot within the absorbing body.

Root-Mean Squared (rms) - The effective value, or the value associated with 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.

Scattered Radiation - An electromagnetic field resulting from currents induced in a secondary, conducting, or dielectric object by electromagnetic waves incident on that object from one or more primary sources.

Short-term Exposure - Exposure for durations less than the corresponding averaging time.

Specific Absorption (SA) - The quotient of the incremental energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume (dV) of a given density (ρ).

$$SA = \frac{dW}{dm} = \frac{dW}{\rho dV}$$

The specific absorption is expressed in units of joules per kilogram (J/kg).

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Specific Absorption Rate (SAR) - The time derivative of the incremental energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume element (*dV*) of given density (ρ).

$$SAR = \frac{d}{dt}\left(\frac{dW}{dm}\right) = \frac{d}{dt}\left(\frac{dW}{\rho dV}\right)$$

SAR is expressed in units of watts per kilogram (W/kg).

Uncontrolled Environment - Locations where there is exposure of individuals who have no knowledge or control of their exposure. The exposures may occur in living quarters or workplaces where there are no expectations that the exposure levels may exceed those shown in Table 3.

Wavelength (λ) - In a monochromatic wave, the distance between two points of corresponding phase of two consecutive cycles in the direction of propagation. The wavelength (λ) of an electromagnetic wave is related to the frequency (f) and velocity (v) by the expression v=f λ. In free space the velocity of an electromagnetic wave is equal to the speed of light, i.e., approximately $3x10^8$ m/s.

4.4 RESPONSIBILITIES

4.4.1 Department/Project/Division Heads are responsible for ensuring that all employees under their direction follow the requirements and procedures in this section.

4.4.2 Supervisors are responsible for the enforcement of the requirements and procedures of this section including:.

A. Ensuring that safe operating procedures pertaining to magnetic fields and RF and microwave operations are established and executed.

B. Providing adequate instructions in safety practices for all personnel who work with or near RF and microwave equipment where any potential exposure could exceed the exposure guidelines (Tables 2 and 3).

C. Making arrangements with the RF Engineering Group to perform surveys immediately following modifications, and at regular intervals (at least annually) of RF and microwave sources, as noted in Paragraph 4.6.4.

D. Ensuring that documented tests are performed on all safety devices (interlocks, signals) when installed and at least annually thereafter.

E. Consulting with Industrial Hygiene and the RF Engineering Group before RF or microwave equipment is installed or extensively modified. Maintenance or repair of established equipment is excepted.

F. Providing copies of all conducted surveys and operating procedures to Industrial Hygiene.

4.4.3 Users are responsible for complying with the provisions of this section.

4.4.4 The Occupational Medicine Office is responsible for notifying the employee, the immediate supervisor, and Industrial Hygiene when any deviation from normal health is observed that may be work-related.

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4.4.5 Industrial Hygiene (IH) is responsible for assisting in the implementation of this section. Specifically:

A. IH shall assist in establishing safety guidelines pertaining to RF and microwave-producing equipment.

B. IH shall review and appraise safety procedures for the use of RF and microwave power-producing equipment.

C. IH shall assist in providing adequate instruction in safety procedures to users who work with or may be exposed to RF and microwave radiation.

D. IH shall maintain copies of all RF leakage survey data for at least one year. Users will supply this data.

4.4.6 The RF Engineering Group is responsible for:

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A. Developing and maintaining an RF Surveyor Training Standard to ensure proper training for personnel performing RF leakage surveys. This training shall include at a minimum:

1. Definitions and hazards pertaining to RF radiation
2. Locations of possible RF emanations for sources to be surveyed
3. Proper use of RF monitoring equipment
4. Proper controls for safe access to RF generating equipment.

B. Training RF Surveyors to perform RF leakage surveys.

C. Performing leakage surveys of all RF equipment at least annually and after extensive modifications to systems. This activity may be delegated to other Trained RF Surveyors outside the Group as appropriate.

D. Providing copies of all RF leakage survey results to Industrial Hygiene.

E. Training and/or Qualifying, as necessary, RF Technicians to safely perform work on RF equipment. This training will at a minimum include all items in paragraph 4.4.6.A above.

4.5 REQUIREMENTS

4.5.1 Protection against the following must be provided:

A. Thermal - Since radiation in the frequency range of 10 MHz to 300 GHz is not energetic enough to produce ionization in living organisms, it is generally accepted that the principal effect of absorption of this energy is a rise in internal temperature.

B. Ancillary hazards, which arise from the generating equipment used to produce radiant energy at significant levels, include:

1. High voltage on components that are on or near the radiating elements.
2. Electric arcing to conducting surfaces from radiating elements at close range.
3. High-power, RF-induction heating units inducing high current in metal objects placed near the radiating element. Although the radiation itself may be harmless, the unexpected intense heat in the object could cause severe burns.
4. Burns to the skin by direct contact with RF potentials.

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5. Radiation from RF and microwave equipment inducing energy in another apparatus that can interfere with operation of associated circuits including control circuits, bioelectronic implants (such as pacemakers), and ionizing radiation survey instruments.

C. Electrical Hazards - In addition to the hazards identified above, electrical hazards include or are a consequence of:

1. Inadequate shock-reaction space;
2. Induced voltages in closed magnetic circuits;
3. High impedances in grounding conductors;
4. Improper lockout/tagout practices;

4.5.2 RF & Microwave Equipment Electrical Safety

The requirements of this subsection are supplementary to ES&H Manual, Section 2.0, "Electrical Safety." Examples of electrical safety equipment include:

A. Fail-safe Control Systems

B. Barriers and Safety Interlocks

C. Safety Interlocks for Transmission Lines

D. Remote-control Interlocks

E. Warning Systems and Annunciators

F. Grounding Methods

G. Temporary By-passing of Safety Interlocks

H. Personnel Protective Equipment (PPE)

4.5.3 Design and Construction Practices

Ancillary apparatus for RF and microwave equipment shall be designed and constructed in accordance with the following safety requirements:

A. A fail-safe control system shall be included, which maintains the desired protective function when a single mechanical or electrical component fails, or upon the failure of its power system, causing the system to go into, or remain in, a safe mode.

B. Fail-safe control systems shall be successfully analyzed before completion of the design.

C. Energy barriers, where required and readily removable (no tools required), shall have their positions monitored by initial control devices, such as limit, photocell, or proximity switches, and shall be considered part of the personnel safety interlock system for the RF/microwave equipment.

D. Equipment and service access-door positions shall be monitored where required by initial control devices having hard-wired final control elements arranged to de-energize the power supply for the RF/microwave equipment upon unauthorized access attempts.

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E. Remote control of RF/microwave operation shall be delegated by sequentially-keyed locally-remote control stations. The sequential keying shall be considered part of the personnel-safety interlock (PSI) system for the RF/microwave equipment.

F. Visual indicators and annunciators used in RF activation warning systems shall have self-checking features, such as push-to-test lights, included in the system design.

G. Where single-point grounding systems are used with RF/microwave power supplies, systems, or structures, their design criteria shall be documented and approved by Electrical Safety of the ES&H Division. Covered copper braid or flat copper bar shall be considered for use as grounding conductors in circuits having fast rise-times.

4.5.4 Operating Criteria

Ancillary apparatus for RF/microwave equipment shall be operated in accordance with the following safety requirements.

A. A fail-safe control system shall be included, which maintains the desired protective function when a single mechanical or electrical component fails, or upon the failure of its power system, causing the system to go into, or remain in, a safe mode.

B. RF/microwave equipment safety training shall include capacitor bank accessor certification, where applicable, and orientation to the safety tagging procedures of PPPL Procedure ESH-016.

C. Periodic safety inspections shall be performed on personnel safety interlock systems and capacitor banks within operational RF/microwave systems as required by PPPL procedures.

4.5.5 Maximum Permissible Exposure (MPE)

A. The maximum permissible exposure (MPE) for controlled environment guidelines adopted by PPPL are noted in Table 2 and Figure 1. (These guidelines follow IEEE C95.1-1999). For human exposure to electromagnetic energy in controlled environments at radio frequencies from 3 kHz to 300 GHz, the MPE, in terms of rms electric (E) and magnetic (H) field strengths, the equivalent plane-wave free-space power densities (S), and the induced currents (I) in the body that can be associated with exposure to such fields, is given in Table 2 as a function of frequency. Exposure associated with a controlled environment includes: exposure that may be incurred by persons who are aware of the potential for exposure as a concomitant of employment, exposure of other cognizant individuals, or exposure that is the incidental result of passage through areas where analysis shows the exposure levels may be above those shown in Table 3 but do not exceed those in Table 2, and where the induced currents may exceed the values in Table 3, Part B, but do not exceed the values in Table 2 Part B. . Figure 1 is a graphic representation of maximum permissible exposure in terms of power density for controlled and uncontrolled environment. This figure is a combination of Tables 2 and 3 for PPPL using E field values only.

1. The MPEs 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 MPEs can be relaxed as described in Paragraph 4.5.8. In non-uniform fields, spatial peak values of field strengths may exceed the MPEs if the spatially averaged value remains within the specified limits. The MPEs may also be relaxed by reference to SAR limits in Paragraph 4.5.6-A by appropriate calculations or measurements.

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2. The MPE refers to values averaged over any six-minute period for frequencies less than 15 GHz and over shorter periods for higher frequencies down to 10 s at 300 GHz, as indicated in Table 2.

3. For near-field exposures at frequencies less than 300 MHz, the applicable MPE is in terms of rms electric and magnetic field strength, as given in Table 2, columns 2 and 3. For convenience, the electric and magnetic field measurements for the MPE may be expressed as equivalent plane-wave power density, given in Table 2, column 3. [See Section 4.3 Definitions: Power Density (S).]

4. For exposures to pulsed radio-frequency fields, in the range of 0.1 to 300,000 MHz, the peak (temporal) value of the MPE in terms of E field is 100 kV/m.

B. The maximum permissible exposure (MPE) guidelines for uncontrolled environment adopted by PPPL are noted in Table 3 and Figure 1. (These guidelines follow IEEE C95.1-1999.) For human exposure to electromagnetic energy in uncontrolled environments at radio frequencies from 3 kHz to 300 GHz, the MPE, in terms of rms electric (E) field strengths, the equivalent plane-wave free-space power densities (S) and the induced currents (I) in the body that can be associated with exposure to such fields are given in Table 3 as a function of frequency. Exposure associated with an uncontrolled environment is the exposure of individuals who have no knowledge or control of their exposure. The exposures may occur in living quarters or workplaces where there are no expectations that the exposure levels may exceed those shown in Table 3.

1. The MPEs 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 limits can be relaxed, as described in Paragraph 4.5.8. In non-uniform fields, spatial peak values of field strengths may exceed the MPEs if the spatially averaged value remains within the specified limits. The MPEs may also be relaxed by reference to SAR limits in Paragraph 4.5.6-B by appropriate calculation or measurement.

2. The MPE refers to values averaged over any six-minute to thirty-minute period for frequencies up to 3,000 MHz, and over shorter periods for higher frequencies, down to 10 s at 300 GHz, as indicated in Table 3.

3. For near-field exposures at frequencies less than 300 MHz, the applicable MPE is in terms of rms electric field strength, as given in Table 3, column 2. For convenience, the MPE may be expressed as equivalent plane-wave power density, given in Table 3, column 3.

4. For exposures to pulsed radio frequency fields in the range of 0.1 to 300,000 MHz, the peak (temporal) value of the MPE, in terms of E field, is 100 kV/m.

C. Regulations governing microwave-oven leakage provide for a limit of 1 mW/cm2 at a distance of 5 cm from the surface of a new oven and a limit of 5 mW/cm2 measured the same way throughout the useful lifetime of the unit (Ref. 4.9.1).

4.5.6 Exclusions

A. For Controlled Environment - At frequencies between 100 kHz and 6 GHz, the MPE in controlled environments for electromagnetic-field strengths may be exceeded if:

1. The exposure conditions can be shown by appropriate techniques to produce specific absorption rates (SARs) below 0.4 W/kg as averaged over the whole body and spatial

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peak SAR, not exceeding 8 W/kg as averaged over any 1 g of tissue (defined as a tissue volume in the shape of a cube), except for the hands, wrists, feet and ankles where the spatial peak SAR shall not exceed 20 W/kg, as averaged over any 10 g of tissue (defined as a tissue volume in the shape of a cube).

2. The SARs are averaged over any six-minute interval. Above 6 GHz, the relaxation of the MPE under partial body-exposure conditions is permitted (see 4.5.8). At frequencies between 0.003 and 0.1 MHz, the SAR exclusion rule, stated above, does not apply. Refer to IEEE 95.1-1999 for more details.

B. For Low-Power Devices in Controlled Environment - This exclusion, consistent with the provision of 4.5.6-A, pertains to devices that emit RF energy under the control of an aware user. This exclusion addresses exposure of the user. For such devices, the exposure of other persons in the immediate vicinity of the user will meet the exclusion criterion for the uncontrolled environment (See 4.5.6-C).

1. At frequencies between 100 kHz and 450 MHz, the MPE may be exceeded if the radiated power is 7 W or less.

2. At frequencies between 450 and 1,500 MHz, the MPE may be exceeded if the radiated power is 7 (450/f) W or less where f is the frequency in MHz.

3. This exclusion does not apply to devices with the radiating structure maintained within 2.5 cm of the body.

C. For Uncontrolled Environments - At frequencies between 100 kHz and 6 GHz, the MPE in uncontrolled environments for electromagnetic-field strengths may be exceeded if:

1. The exposure conditions can be shown by appropriate techniques to produce SARs below 0.08 W/kg, as averaged over the whole body, and spatial peak SAR values not exceeding 1.6 W/kg, as averaged over any 1 g of tissue (defined as a tissue volume in the shape of a cube), except for the hands, wrists, feet and ankles where the spatial peak SAR shall not exceed 4 W/kg, as averaged over any 10 g of tissue (defined as a tissue volume in the shape of a cube).

2. The averaging time for SARs is as indicated in Table 3. Above 6 GHz, the relaxation of the MPE under partial-body exposure conditions is permitted (see 4.5.8).

3. At frequencies between 0.003 and 0.1 MHz, the SAR exclusion rule does not apply. Refer to IEEE 95.1 - 1999 (Ref. 4.9.4) for more details.

D. For Low-Power Devices in Uncontrolled Environment - This exclusion, consistent with the provisions of Paragraph 4.5.6-C, pertains to devices that emit RF energy without control or knowledge of the user.

1. At frequencies between 100 kHz and 450 MHz, the MPE may be exceeded if the radiated power is l.4 W or less.

2. At frequencies between 450 and 1,500 MHz, the MPE may be exceeded if the radiated power is l.4 (450/f) W or less where f is the frequency in MHz.

3. This exclusion does not apply to devices with the radiating structure maintained within 2.5 cm of the body.

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4.5.7 Measurements

A. For both pulsed and non-pulsed fields at frequencies below 300 MHz, the power density, the square of the field strengths, and the SARs, as applicable, are averaged over any six-minute or thirty-minute period. The time-averaged values should not exceed those given in Tables 2 and 3, or the exclusions in Paragraph 4.5.6. Note that the averaging time is a function of frequency above 15 GHz for a controlled environment and is a function of frequency between 1.34 and 3.0 MHz above 3 GHz for an uncontrolled environment.

B. Generally, for frequencies less than 300 MHz, both the electric and magnetic field strengths shall be determined. For frequencies equal to or less than 30 MHz, this can only be accomplished by independent measurement of both the electric and magnetic field strengths. For frequencies between 30 and 300 MHz, it may be possible through analysis to show that measurement of one of the two fields, not both, is sufficient for determining compliance with the MPE. For frequencies above 300 MHz, only one field component need be measured (generally E).

C. Measurements to determine adherence to the recommended MPE shall be made (with appropriate instruments) at distances 20 cm or greater from any object [see IEEE C95.3-1999].

4.5.8 Relaxation of Power-Density Limits for Partial-Body Exposures

Compliance with the MPE of Tables 2 and 3 is determined from spatial averages of power density or the mean squared electric and magnetic-field strengths over an area equivalent to the vertical cross-section of the human body (projected area) at a distance no closer than 20 cm from any object. The relaxation of power-density limits is allowed for exposure of all parts of the body except for the eyes and the testes. For the relaxation of partial body exposure for controlled and uncontrolled environments, refer to the IEEE Standard C95.1, 1999 for the maximum, allowable, exposure-power, density limits.

4.6 PRACTICES AND PROCEDURES

Equipment emitting RF and microwave radiations shall be operated in a manner such that exposure to operators and other personnel is minimized. In no case shall exposure exceed the limits stated in Paragraph 4.5.5. Three factors -- time, distance, and shielding -- can be utilized to minimize radiation hazards. RF and microwave radiation shall be subject to the following controls:

4.6.1 Administrative Controls

A. Access to RF/microwave areas shall be limited to qualified personnel. Signs and other visible and/or audible signals shall be used. The ANSI warning symbol (Appendix I) for non-ionizing radiation shall be included on all postings used to identify radiation areas. Industrial Hygiene and the RF Engineering Group shall check for proper posting of signs.

B. Areas shall be posted according to the following guidelines:

1. Notice signs should be posted at the point of access to an area where RF emissions MAY exceed the Uncontrolled Area exposure limits.

2. Caution signs shall be posted in areas where the RF emissions exceed the Uncontrolled Area limits on a regular basis.

3. Warning signs shall be posted in advance of areas that have RF emissions levels that exceed the Controlled Area limits.

4. Danger signs shall be posted in areas that have the potential to exceed the Controlled Area limits unless precautions are taken.

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C. Devices with directional beams of radiation shall be positioned so that energy is harmlessly absorbed and not directed into any occupied area.

D. Personnel shall not be permitted to make close visual examinations of energized microwave radiators and reflectors.

E. Personnel are not permitted to enter areas exceeding controlled area emissions without proper training from the RF Engineering Group and the approval of Industrial Hygiene.

4.6.2 Design and Construction Criteria for Original Equipment

A. Shielding and other control measures shall be provided to minimize radiation leakage.

B. Exposed dummy loads shall be appropriately guarded to prevent burns.

C. Adequately sized electrical-ground connections shall be provided.

D. Sharp edges or points on equipment should be eliminated to avoid corona discharge.

E. RF and microwave-heating equipment shall be designed with adequate clearances around RF leads.

F. Where possible, bypass capacitors should be provided on control power and instrument leads that enter the RF compartment to control leakage without interfering with proper operation.

G. Viewing ports, air inlets and outlets, etc., shall be designed and/or shielded to limit leakage radiation to acceptable levels (Table 2).

H. Consideration shall be given to potential X-ray production in RF-generating equipment. Shields or barriers shall be designed into applicable system to minimize personnel exposure to these ionizing radiations. If ionizing radiation generation is possible for a system, contact Health Physics for monitoring and proper control methods.

4.6.3 Engineering Controls

A. Barriers and interlocks shall be used to prevent operators and maintenance personnel from accidentally entering areas where radiation and ancillary hazards exist.

B. Whenever tests are performed, radiating elements shall be replaced with dummy loads, where appropriate.

C. Whenever the potential for excessive radiation in occupied locations exists, area monitoring equipment should be considered as a fixed part of the installation.

D. When possible, the energizing switch for the equipment should be controlled by a preset elapsed-time mechanism to limit the exposure period automatically.

4.6.4 Surveys

A. RF surveys are required on all new installations and when modifications are made that affect wave guides, RF generation, coax lines, or other forms of RF transmission, and at least annually on all other RF emitting equipment. If equipment is not in use on the regularly scheduled survey date, the equipment shall be surveyed during the next start-up.

B. The survey shall be conducted by a Qualified RF technician (paragraph 4.4.6). A copy of the survey shall be sent to Industrial Hygiene.

C. Survey documentation should include as a minimum:

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1. A sketch that indicates the RF source and survey measurement locations.
2. Whether the measurement is in the near or far field.
3. The instrument used, its type, model, serial number, and most recent calibration date. Calibration should be no older than one year.
4. Survey data and any recommendations.
5. An indication of whether the RF energy leakage meets or exceeds the MPE or the levels for Uncontrolled Areas.

E. RF and microwave-survey meters shall be calibrated at least annually.

F. Microwave ovens must be kept in a clean and sanitary manner. Damage to the door seals of the microwave, or to the microwave itself, must be reported to Industrial Hygiene. IH will perform a RF leakage survey of any microwave suspected of damage.

G. Where the potential for X-radiation generation exists, the Health Physics Branch shall be requested to survey the installation and make any appropriate shielding or operational limitation recommendations.

4.7 MAGNETIC FIELD SAFETY

4.7.1 There are no regulatory limits on static-magnetic field exposure to date, only guidelines. PPPL follows the voluntary guidelines of the Department of Energy (DOE) for static-magnetic field exposure, which is summarized in Table 1. The intent of this table is not to establish a fixed standard, but rather to provide safety factors for those working with high-magnetic fields until quantitative data are established. However, exposure to magnetic-field values greater than those listed in Table 1 must be approved by the PPPL Deputy Director and Industrial Hygiene on a case-by-case basis.

Table 1

U.S. Department of Energy Voluntary Guidelines for Maximum Exposure to Static Magnetic Fields

Work Time	8 hr. workday	1 hr. or less	10 min. or less
Body Part			
Whole Body or Head	100 G	1,000 G	5,000 G
Extremities	1,000 G	10,000 G	20,000 G
Note: 10,000 G = 1 Tesla			

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4.8 SAFETY RESTRICTIONS FOR PACEMAKER WEARERS

4.8.1 Heart pacemakers have been shown to respond to electromagnetic fields including RF and microwave in ways, which could have an adverse affect on pacemaker wearers. In order to protect personnel who wear pacemakers, access to the following areas is prohibited:

A. Where magnetic fields may exceed 10 gauss.

B. Within 5 feet of arc welding devices.

C. Vicinity of open-flux magnets and other devices, as posted.

*Access to generally restricted areas by pacemaker wearers will be considered on a case-by-case basis if monitoring data is available and after consulting with the Supervisor, the PPPL Deputy Director, the Occupational Medicine Office, and with IH review and approval.

4.8.2 Areas where pacemaker restrictions apply shall be posted by IH.

4.8.3 Subcontractors, visitors, and members of tour groups who wear pacemakers will also be prohibited from entering these areas.

4.8.4 There is no prohibition against pacemaker wearers being near microwave ovens. Modern pacemakers are sufficiently well designed and microwave ovens sufficiently free of RF leakage that problems are not expected to arise.

4.8.5 Wearers of pacemakers should make themselves known to supervisors and to the Occupational Medicine Office. Supervisors are asked to cooperate by providing work-area reassignments for these individuals, if necessary.

4.8.6 Supervisors or employees who have questions about electromagnetic-field effects on pacemakers should contact Industrial Hygiene or the Occupational Medicine Office.

4.9 REFERENCES

4.9.1 CFR 21, Food and Drugs (4/1/92), Subchapter J, Part 1030, pp. 496-499, "Performance Standards for Microwave and Radio Frequency Emitting Products."

4.9.2 CFR 29, Labor (9/2/92) Chap.1, Part 1910, Occupational Safety and Health Standards (OSHA) Subpart G, "Occupational Health & Environmental Control"; Part 1910.97 p. 228, "Non-ionizing Radiation"; Part 1910.99, p. 230, "Source of Standards."

4.9.3 CFR 47, Telecommunications (10/1/91), Chapter 1, "Federal Communications Commission (FCC)," Subchapter A, Part 15, "Radio frequency Devices," p. 526; and Part 18, "Industrial, Scientific, and Medical Equipment," pp. 591 through 598.

4.9.4 IEEE C95.1-1999, "Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields," 3 kHz to 300 GHz (Replaces ANSI C95.1-1982).

4.9.5 IEEE C95.2-1999, “IEEE Standard for Radio Frequency Energy and Current Flow Symbols”

4.9.6 “Radio-Frequency and Microwave Radiation”, Second Edition, American Industrial Hygiene Association Publications, 1994.

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Table 2
Maximum Permissible Exposure for Controlled Environments

Part A: Electromagnetic Fields*

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) E-field, H-field (mW/cm^2)	Averaging Time (minutes)
0.003-0.1	614	163	100, 1,000,000	6
0.1-3.0	614	$16.3 / f$	$100, 10{,}000 / f^2$	6
3-30	$1{,}842/f$	$16.3 / f$	$900/f^2, 10{,}000 / f^2$	6
30-100	61.4	$16.3 / f$	$1.0, 10{,}000 / f^2$	6
100-300	61.4	0.163	1.0	6
300-3,000	–	–	$f/300$	6
3,000-15,000	–	–	10	6
15,000-300,000	–	–	10	$616{,}000/f^{1.2}$

f = frequency in MHz

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

Microwave ovens operate at 2450 MHz and have an exposure limit of 1 mW/cm2 for new units and 5 mW/cm2 thereafter.

Part B: Induced and contact radio frequency currents*			
Frequency Range (MHz)	**Maximum Current (mA)**		**Contact**
	Through both feet	**Through each foot**	
0.003-0.1	$2000\ f$	$1000f$	$1000f$
0.1-100	200	100	100
Note – f is the frequency in MHz			

*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.

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Table 3
Maximum Permissible Exposure for Uncontrolled Environments

Part A: Electromagnetic Fields*

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time (minutes)
0.003-0.1	614	163	100	6
0.1-1.34	614	$16.3 / f$	100	6
1.34-3.0	$823.8/f$	$16.3 / f$	$180/f^2$	$f^2/0.3$
3.0-30	$823.8/f$	$16.3 / f$	$180/f^2$	30
30-100	27.5	$158.3 / f^{1.668}$	0.2	30
100-300	27.5	0.0729	0.2	30
300-3,000	–	–	$f/1{,}500$	30
3,000-15,000	–	–	$f/1{,}500$	$90{,}000/f$
15,000-300,000	–	–	10	$616{,}000/f^{1.2}$

f = frequency in MHz

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

Microwave ovens operate at 2450 MHz and have an exposure limit of 1 mW/cm2 for new units and 5 mW/cm2 thereafter.

Part B: Induced and contact radio frequency currents*			
Frequency Range (MHz)	**Maximum Current (mA)**		**Contact**
	Through both feet	**Through each foot**	
0.003-0.1	$900f$	$450f$	$450f$
0.1-100	90	45	45
Note – f is the frequency in MHz			

*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.

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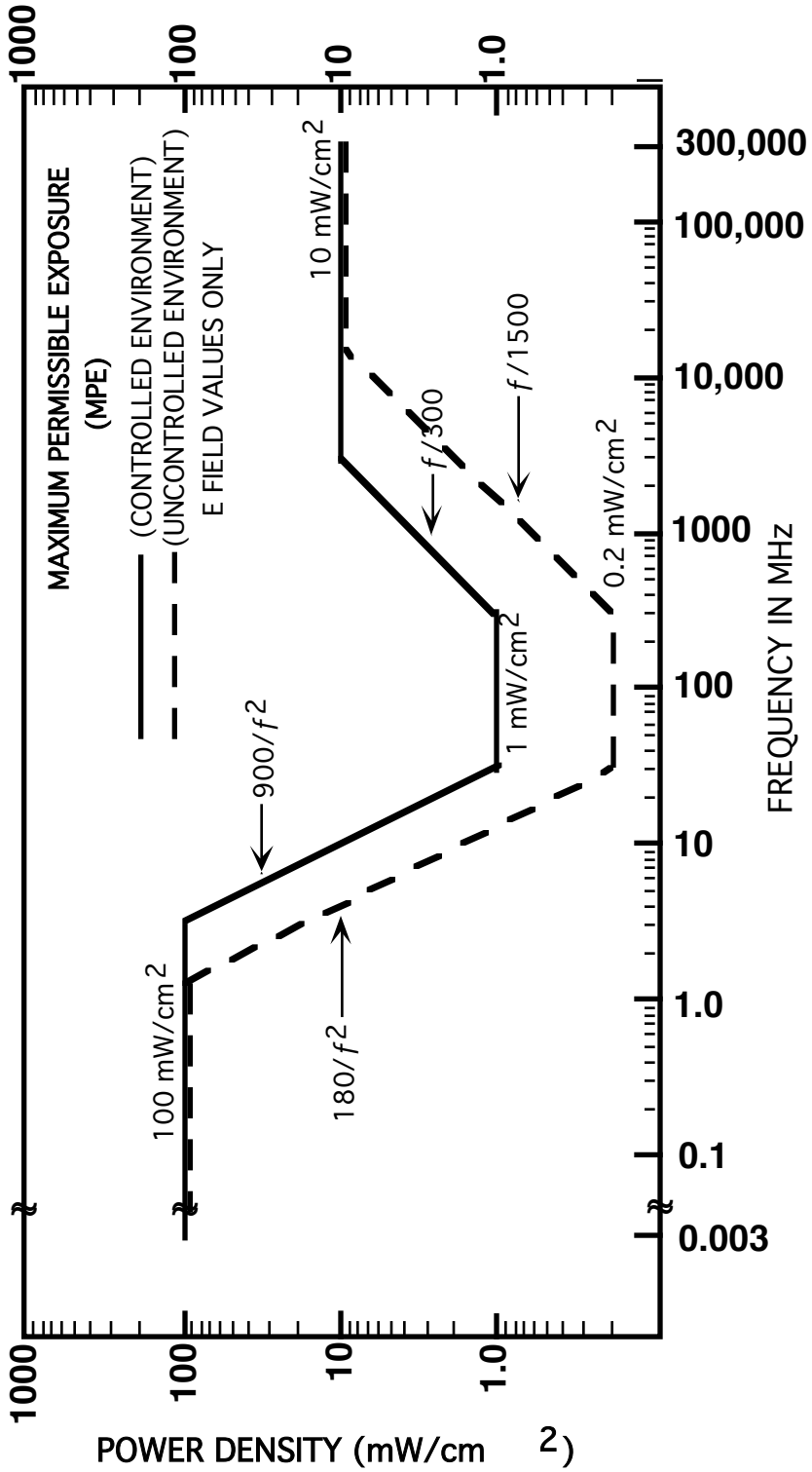
Figure 1

Maximum Permissible Exposure (MPE) Levels for Controlled and Uncontrolled Environments



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APPENDIX I

WARNING SIGNS

The warning symbol for identifying incident-electromagnetic energy consists of a black wave front radiating from a stylized point-source antenna on a white background. This symbol may be used as a part of safety signs that conform with danger caution, and notice as specified in ANSI Z535.2-1991.

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