



Health Santé
Canada Canada

**Limits of Human Exposure to
Radiofrequency Electromagnetic Fields
in the Frequency Range from
3 kHz to 300 GHz**

Safety Code 6

Archived

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Our mission is to help the people of Canada
maintain and improve their health.

Health Canada

Preface

This document is one of a series of Safety Codes prepared by the Radiation Protection Bureau of Health Canada. These Safety Codes specify the requirements for the safe use of radiation emitting devices. This Code replaces the previous Safety Code 6, EHD-TR-160, published in 1991 and reprinted in 1994 as 93-EHD-160. The rationale for changes to the previous Safety Code is given in Appendix VII.

The aim of this Code is to set out safety requirements for the installation and use of radiofrequency (RF) and microwave devices that operate in the frequency range from 3 kHz to 300 GHz. The exposure criteria in this Code are not intended to apply to the deliberate exposure for treatment purposes of patients by, or under the direction of, practitioners in the healing arts.

The safety procedures and installation guidelines given in this Code are for instructing and guiding employees of federal government departments and agencies. These guidelines may be adopted by the provinces, industry or other interested parties. The Department of National Defence shall conform to the requirements of this Safety Code, except in such cases where it considers such compliance would have a detrimental effect on its activities in support of training and operations of the Canadian Forces.

The objective of this Code is to establish guidelines for limiting RF and microwave exposure. As such, the document does not describe techniques for product performance evaluation. However, some basic principles and methods for evaluation of exposure levels are included in order to assist readers who are not familiar with RF measurements and evaluation. The Bureau recommends that organizations which adopt this Code develop their own procedures for compliance and exposure evaluation.

In a field where technology is advancing rapidly and where unexpected and unique problems may occur, this Code cannot cover all possible situations and blind adherence to rules cannot substitute for the exercise of sound judgement. Consequently, specifications and recommendations in this Code may require some modifications under certain circumstances. This, however, should be done in consultation with experts competent in the field of RF radiation protection. This Code will be reviewed and revised periodically and a particular

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requirement may be reconsidered at any time if it is found necessary. Interpretation or elaboration on any point can be obtained from the Non-Ionizing Radiation Section of the Radiation Protection Bureau (RPB) in Ottawa.

The draft of the revision of this Code was prepared by Dr. A. Thansandote with the assistance of Mr. D.W. Lecuyer, Mr. G.B. Gajda and Dr. J. P. McNamee, all of whom are with the Consumer and Clinical Radiation Hazards Division, RPB. The draft is based on the previous versions of this Safety Code as well as the most current scientific information. This draft was reviewed by P.J. Waight, M.D., S. Vlahovich, M.D., Mr. P. Dvorak, Mr. W.J. Welsh, Mr. H.P. Maharaj and Dr. J.R.N. McLean of RPB, and by Dr. O.P. Gandhi of the University of Utah and Dr. M.A. Stuchly of the University of Victoria. Dr. K.S. Tan of the Medical Devices Bureau provided comments for Section 3.4 (Medical Devices and Electromagnetic Interference).

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A. Federal Departments and Agencies

1. Health Canada, Occupational Health and Safety Agency
2. Transport Canada
3. Industry Canada, Spectrum Engineering Branch
4. Canadian Coast Guard
5. National Defence, Quality Engineering Test Establishment
6. Communications Research Centre, Radio Communications and Broadcast Research

B. Provinces

1. British Columbia Ministry of Health, Radiation Protection Branch
2. The Manitoba Cancer Treatment and Research Foundation, Department of Medical Physics
3. Ontario Ministry of Labour, Occupational Health and Safety Branch, Radiation Protection Service
4. Alberta Labour (Represented by d.r. Novitsky Enterprises)

C. Industry

1. Motorola, Florida Corporate Electromagnetics Research Laboratory
2. NAV Canada, Flight Inspection and Radiocommunications Engineering
3. Radio Advisory Board of Canada

D. Other Interested Parties

1. Canadian Centre for Occupational Health and Safety
2. McMaster University, St. Joseph's Hospital

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1. Introduction

Recent developments in the electronics industry have led to the widespread use of radiofrequency (RF) devices in various areas, including telecommunication, radio and television broadcasting, radar, industrial processing, medical applications and consumer products. Electromagnetic fields extend over large areas when generated for communication, broadcasting and radar devices, but generally spread only over small areas when used in industrial, medical and consumer devices. Reflection and scattering of electromagnetic waves and simultaneous RF emissions by more than one source frequently result in a complex condition known as “multi-path” propagation and spatially non-uniform fields.

Studies of possible hazards to human health from exposure to RF electromagnetic fields show that there is a need for controls. Exposure to RF energy in excess of the limits given in this Safety Code may cause adverse health effects. The type and extent of effects depends not only on the strength of the field and the exposure duration, but also on various other factors such as the frequency, type of modulation, polarization, and distance from the source.

The exposure limits were established from a review of experiments conducted over the last 30 years on biological organisms, including humans, animals and cell systems^(1,2,3). The limits recommended in this Code have been set at least a factor of 10 lower than the threshold where potentially harmful effects begin, as judged by a consensus of the scientific community^(4,5). Biological effects of RF fields at levels too low to produce significant heating have also been reviewed^(3,6). These effects are not well established, nor are their implications for human health sufficiently well understood. Thus, they cannot provide a basis for making recommendation towards the restriction of human exposures to such low-intensity RF fields.

SI units are used throughout this document unless specified otherwise. A glossary of definitions is provided in Appendix VIII.

1.1 Purposes of the Code

The purposes of this Code are:

- (a) to specify maximum levels and durations of exposure to RF fields of frequencies between 3 kHz and 300 GHz in order to prevent human health effects;
- (b) to specify maximum allowable RF contact and induced body currents to prevent the physical perception of RF fields to the general public and RF shock or burns to RF and microwave exposed workers;
- (c) to recommend general procedures for ensuring that exposure of the general public and of personnel working in the vicinity of RF and microwave devices is not greater than the levels specified in this Code; and
- (d) to recommend working conditions that will lead to high standards of safety for all personnel engaged in the manufacture, operation and maintenance of RF devices.

2. Maximum Exposure Limits

In the following sections, the maximum exposure levels for both RF and microwave exposed workers (including occupationally exposed persons) and other individuals (including the general public) are specified. These levels shall not be exceeded.

The basic limits which shall not be exceeded are given in terms of the currents in the body, either by induction or contact with energized metallic objects, or in terms of the rate at which RF electromagnetic energy is absorbed in the body. The latter is expressed, more precisely, as the *specific absorption rate (SAR)*, i.e., the rate of RF energy absorption per unit mass in the body. *SAR* has units of joules per second per kilogram or watts per kilogram (W/kg). In practice, direct measurements of *SAR* are feasible only under laboratory conditions. Recommended maximum exposure levels in terms of unperturbed electric and magnetic field strength as well as power density are therefore given in addition to the *SAR* limits. These maximum field intensities are at levels which would generate a *SAR* or induced body current no greater than the basic limit.

For exposure limits of RF and microwave exposed workers, a safety factor of approximately 10 was incorporated with reference to the scientific-consensus threshold for adverse health effects. For other persons including the general public, an additional safety factor (2 to 5) was included to arrive at lower limits. The incorporation of these safety factors is to provide for all possible conditions under which the exposure might occur. The rationale for lower general public limits is as follows:

1. Exposure to the public is potentially 24 hours a day for 7 days a week, compared with 8 hours a day, 5 days a week for RF and microwave exposed workers.
2. Certain members of the general public may be more susceptible to harm from RF and microwave exposure.

To determine whether the maximum exposure levels and durations are exceeded, full consideration shall be given to such factors as:

- (a) occupancy of areas;

(b) actual duration of exposure and time averaging (including ON/OFF times of the RF generators, direction of the beam, duty factors, sweep times, etc.);

(c) spatial characteristics of exposure, i.e., whole body or parts thereof;

(d) uniformity of the exposure field, i.e., spatial averaging.

In certain instances and over a specific frequency range, higher exposure levels are permitted for short durations. If this is the case, the field strengths and power densities should be averaged over one-tenth hour period (0.1 h or 6 min). Graphs are provided in Appendix I for easy identification of maximum exposure levels at various frequencies.

2.1 RF and Microwave Exposed Workers (Including Occupationally Exposed Persons)

In the far-field zone, electric field strength, magnetic field strength and power density are interrelated by simple mathematical expressions (Appendix III). Therefore, any one of these parameters defines the remaining two. In the near-field zone, both the electric and magnetic field strengths shall be measured, since there is no simple relationship between these two quantities. Instrumentation for the measurement of magnetic fields at certain frequencies may not be commercially available. In this case, the electric field strength shall be measured. Field strength measurements are described in Appendix V.

2.1.1 Field Strength Limits

(a) An RF and microwave exposed worker shall not be exposed to electromagnetic radiation in a frequency band listed in Column 1 of Table 1 if the field strength exceeds the value given in Column 2 or 3 of Table 1, when averaged spatially and over time, or if the power density exceeds the value given in Column 4 of Table 1, when averaged spatially and over time. The spatial averaging is carried out over an area equivalent to the vertical cross-section of the human body (projected area). A time-averaging period of 0.1 h (6 min) should be employed for frequencies up to 15 000 MHz. Above these frequencies, a different averaging time is used and is described in Section 2.3.2.

(b) Where the electromagnetic radiation consists of a number of frequencies in the same or different frequency bands shown in

Column 1 of Table 1, then the ratio of the measured value at each frequency to the limit at that given frequency shown in Column 2, 3, or 4 shall be determined and the sum of all ratios thus obtained for all frequencies shall not exceed unity when averaged spatially and over time. For field strength measurements, the measured values and the limits shall be squared before determining the ratios. The limit, as applied to multiple frequencies, can be expressed as:

$$\sum_{f = 3 \text{ kHz}}^{300 \text{ GHz}} R_f \leq 1 ,$$

where f is the frequency for which measurements were taken and, where the electric or magnetic field strength is measured,

$$R_f = \left(\frac{\text{Measured Value of Field Strength at } f}{\text{Exposure Limit of Field Strength at } f} \right)^2 ,$$

or where the power density is measured,

$$R_f = \frac{\text{Measured Value of Power Density at } f}{\text{Exposure Limit of Power Density at } f} ,$$

Table 1
Exposure Limits for RF and Microwave Exposed Workers

1 Frequency (MHz)	2 Electric Field Strength; rms (V/m)	3 Magnetic Field Strength; rms (A/m)	4 Power Density (W/m ²)	5 Averaging Time (min)
0.003–1	600	4.9		6
1–10	600/ f	4.9/ f		6
10 - 30	60	4.9/ f		6
30–300	60	0.163	10*	6
300–1 500	3.54 $f^{0.5}$	0.0094 $f^{0.5}$	$f/30$	6
1 500–15 000	137	0.364	50	6
15 000–150 000	137	0.364	50	616 000 / $f^{1.2}$
150 000–300 000	0.354 $f^{0.5}$	9.4 x 10 ⁻⁴ $f^{0.5}$	3.33 x 10 ⁻⁴ f	616 000 / $f^{1.2}$

* Power density limit is applicable at frequencies greater than 100 MHz.

- Notes:**
1. Frequency, f , is in MHz.
 2. A power density of 10 W/m² is equivalent to 1 mW/cm².
 3. A magnetic field strength of 1 A/m corresponds to 1.257 microtesla (μT) or 12.57 milligauss (mG).

Example 2.1:

After time and spatially averaged measurements, the electric fields to which an RF worker is exposed are found to be 30 V/m, 40 V/m, 50 V/m and 60 V/m at 20 MHz, 90 MHz, 150 MHz and 1300 MHz, respectively. The relative values with respect to the exposure limits in the frequency bands of concern are given as follows:

$$R_1 = (30/60)^2 = 0.25 \quad \text{for 20 MHz (in the frequency band 10–30 MHz)}$$

$$R_2 = (40/60)^2 = 0.44 \quad \text{for 90 MHz (in the frequency band 30–300 MHz)}$$

$$R_3 = (50/60)^2 = 0.69 \quad \text{for 150 MHz (in the frequency band 30–300 MHz)}$$

$$R_4 = (60/127.6)^2 = 0.22 \quad \text{for 1300 MHz (in the frequency band 300–1 500 MHz)}$$

From which $R_1 + R_2 + R_3 + R_4 = 1.6$, which exceeds unity and therefore the combined field strength does not conform with the Safety Code limit. Note that 127.6 V/m comes from substituting $f = 1300$ in the exposure limit term $3.54f^{0.5}$ which is found in Column 2 of Table 1.

Example 2.2:

Assume that a worker is exposed to RF fields at three different frequencies. Exposure measurements were performed, which were time and spatially averaged, producing the following conditions:

0.1 A/m at 27 MHz

70 V/m at 915 MHz

25 W/m² at 10 000 MHz

The relative values with respect to the exposure limits in the frequency bands of concern are given as follows:

$$R_1 = (0.1/0.18)^2 \quad \text{for 27 MHz (in the frequency band 10–30 MHz)}$$

$$R_2 = (70/107.1)^2 \quad \text{for 915 MHz (in the frequency band 300–1 500 MHz)}$$

$$R_3 = 25/50 \quad \text{for 10 000 MHz (in the frequency band 1 500–15 000 MHz)}$$

From which $R_1 + R_2 + R_3 = 0.99$, which is less than unity and therefore the combined field strengths and power density conform with the Safety Code limit.

2.1.2 Basic Restrictions – Specific Absorption Rate (SAR) Limits

SAR, as defined in Appendix VIII, is a measure of the rate at which electromagnetic energy is absorbed in the body. Methods for SAR determination are described in Appendix V. At frequencies between 100 kHz and 10 GHz, SAR limits take precedence over field strength and power density limits and shall not be exceeded.

The SAR should be determined for cases where exposures take place at 0.2 m or less from the source. For conditions where SAR determination is impractical, field strength or power density measurements shall be carried out. In cases where SAR determination is appropriate, the values in Table 2 shall not be exceeded:

Table 2
SAR Limits for RF and Microwave Exposed Workers

Condition	SAR Limit (W/kg)
The SAR averaged over the whole body mass	0.4
The local SAR for head, neck and trunk, averaged over any one gram (g) of tissue*	8
The SAR in the limbs, as averaged over 10 g of tissue*	20

*Defined as a tissue volume in the shape of a cube.

Although not a requirement of the Code, it is suggested that whenever possible, the organ-averaged SAR for the eye not exceed 0.4 W/kg. As stated in Appendix VII, this suggestion shall remain until sufficient scientific information is available to accurately assess the health effects of RF exposure on the eye.

2.1.3 Induced and Contact Current Limits

Limits for induced and contact currents are intended to reduce the potential for RF shock or burns as follows:

(a) For free standing RF and microwave exposed workers (no contact with metallic objects), current induced in the human body by electromagnetic radiation in the frequency bands listed in Column 1 of Table 3 shall not exceed the value given in Column 2 of Table 3. Induced current measurements are described in Appendix V.

(b) No object with which an RF and microwave exposed worker may come into contact by hand grip shall be energized by electromagnetic radiation in the frequency bands listed in Column 1 of Table 3 to such an extent that the current flow through an electrical circuit, having an impedance equivalent to that of the human body, exceeds the value given in Column 3 of Table 3, as measured with a contact current meter. Contact current measurements are described in Appendix V.

Note: The maximum permitted currents may be perceptible (such as a tingling or warming sensation), but are not sufficient to cause any pain or damage such as burns.

(c) Where the electromagnetic radiation consists of a number of frequencies in the same or different frequency bands, shown in Column 1 of Table 3, the ratio of the square of the measured current in each frequency to the square of the limit at that given frequency, shown in Column 2 or 3 (depending on whether it is induced or contact current) shall be determined, and the sum of all ratios thus obtained for all frequencies shall not exceed unity when time averaged. The limit, as applied to multiple frequencies, can be expressed as

$$\sum_{f = 3 \text{ kHz}}^{110 \text{ MHz}} r_f \leq 1 ,$$

where f is the frequency for which measurements were taken and

$$r_f = \left(\frac{\text{Measured Time-Averaged Value of Current at } f}{\text{Current Limit at } f} \right)^2 ,$$

Table 3
Induced and Contact Current Limits for RF and Microwave Exposed Workers

1 Frequency (MHz)	2 Induced Current (rms) (mA) Through		3 Rms Contact Current (mA) Hand Grip and Through Each Foot	4 Averaging Time
	Both Feet	Each Foot		
	0.003–0.1	2000 f		
0.1–110	200	100	100	0.1 h (6 min)

- Notes:**
1. Frequency, f , is in MHz.
 2. The above limits may not adequately protect against startle reactions and burns caused by transient spark discharges for intermittent contact with energized objects.

(d) For frequencies between 3 kHz and 100 kHz, the averaging time to be applied to the induced and contact currents shall be 1 second(s). For frequency between 100 kHz and 110 MHz, time averaging shall be applied to the square of the induced and contact currents and shall be consistent with the averaging time in Table 1 (0.1 h or 6 min), provided that the time-averaged square of the current in any 0.1 h (6 min) period does not exceed the limit given in the following relation:

$$I_{av}^2 = I_{lm}^2 \frac{6}{T_{exp}} ,$$

where I_{av} is the maximum allowable time-averaged current for exposure times less than 0.1 h (6 min), I_{lm} is the current limit through each foot (100 mA) as specified in Table 3, and T_{exp} is the exposure time in minutes during any 0.1 h (6 min) period. Shown in Table 4 are the higher values of I_{av} that may be allowed for exposure times less than 0.1 h (6 min).

Table 4
Time-Averaged Induced and Contact Current Limits for Different Exposure Times for the Frequency Band 0.1–110 MHz: RF and Microwave Exposed Workers

Exposure Time (Min)	6-Minute, Time-Averaged Induced/Contact Current (rms) through Each Foot (mA)
6	100
5	110
4	123
3	141
2	173
1	245
0.5	346*

* Maximum instantaneous current for exposure times less than 0.5 min. is 350 mA.

Note: The above limits may not adequately protect against startle reactions and burns caused by transient spark discharges for intermittent contact with energized objects.

To limit the temperature rise in the extremities such as ankles or wrists of the exposed individuals for exposure times less than 0.5 min, a maximum instantaneous current of 350 mA shall not be exceeded⁽⁷⁾.

Example 2.3:

Assume that the time-averaged induced currents through both feet of an RF worker were found to be 5 mA, 80 mA and 120 mA at 0.005 MHz, 0.06 MHz and 1 MHz, respectively. The relative values with respect to the current limits in the frequency bands of concern are given as:

$$r_1 = (5/10)^2 = 0.25 \quad \text{for 0.005 MHz (in the frequency band 0.003–0.1 MHz)}$$

$$r_2 = (80/120)^2 = 0.44 \quad \text{for 0.06 MHz (in the frequency band 0.003–0.1 MHz)}$$

$$r_3 = (120/200)^2 = 0.36 \quad \text{for 1 MHz (in the frequency band 0.1–110 MHz)}$$

From which $r_1 + r_2 + r_3 = 1.05$, which exceeds unity and therefore the total current through both feet does not conform with the Safety Code limit. Note that 10 mA and 120 mA come from substituting $f = 0.005$ and 0.06 , respectively, in the exposure limit term $2000f$ which is found in Column 2 of Table 3.

2.1.4 Peak Field Strength Limit for Pulsed Fields

For exposures to pulsed electromagnetic fields in the frequency range of 0.1 to 300 000 MHz, the peak value of the instantaneous field (temporal peak), in terms of electric field strength, shall not exceed 100 kV/m. For pulse duration less than 100 ms, and in the preceding frequency range, peak limits shall be derived using the formula given in Appendix IV. If the derived peak limits are greater than 100 kV/m, the exposure limit shall be taken as 100 kV/m.

2.2 Exposure of Persons Not Classified as RF and Microwave Exposed Workers (Including the General Public)

2.2.1 Field Strength Limits

(a) A person other than an RF and microwave exposed worker shall not be exposed to electromagnetic radiation in a frequency band listed in Column 1 of Table 5, if the field strength exceeds the value given in Column 2 or 3 of Table 5, when averaged spatially and over

time, or if the power density exceeds the value given in Column 4 of Table 5, when averaged spatially and over time. The spatial averaging is carried out over an area equivalent to the vertical cross-section of the human body (projected area). A time-averaging period of 0.1 h (6 min) should be employed for frequencies up to 15 000 MHz. Above these frequencies, a different averaging time is used and is described in Section 2.3.2.

(b) Where the electromagnetic radiation consists of a number of frequencies in the same or different frequency bands, shown in Column 1 of Table 5, then the ratio of the measured value at each frequency to the limit at that given frequency shown in Column 2, 3, or 4 shall be determined, and the sum of all ratios thus obtained for all frequencies shall not exceed unity when averaged spatially and over time. For field strength measurements, the measured values and the limits shall be squared before determining the ratios. See Section 2.1.1 for more details on calculating the sum.

**Table 5
Exposure Limits for Persons Not Classified As RF and Microwave Exposed Workers (Including the General Public)**

1 Frequency (MHz)	2 Electric Field Strength; rms (V/m)	3 Magnetic Field Strength; rms (A/m)	4 Power Density (W/m ²)	5 Averaging Time (min)
0.003–1	280	2.19		6
1–10	280/f	2.19/f		6
10–30	28	2.19/f		6
30–300	28	0.073	2*	6
300–1 500	1.585f ^{0.5}	0.0042f ^{0.5}	f/150	6
1 500–15 000	61.4	0.163	10	6
15 000–150 000	61.4	0.163	10	616 000 /f ^{1.2}
150 000–300 000	0.158f ^{0.5}	4.21 x 10 ⁻⁴ f ^{0.5}	6.67 x 10 ⁻⁵ f	616 000 /f ^{1.2}

* Power density limit is applicable at frequencies greater than 100 MHz.

- Notes:**
1. Frequency, f , is in MHz.
 2. A power density of 10 W/m² is equivalent to 1 mW/cm².
 3. A magnetic field strength of 1 A/m corresponds to 1.257 microtesla (μT) or 12.57 milligauss (mG).

2.2.2 Basic Restrictions – Specific Absorption Rate (SAR) Limits

SAR, as defined in Appendix VIII, is a measure of the rate at which electromagnetic energy is absorbed into the body. Methods for SAR determination are described in Appendix V. At frequencies between 100 kHz and 10 GHz, SAR limits take precedence over field strength and power density limits and shall not be exceeded.

The SAR should be determined for cases where exposures take place at 20 cm or less from the source. For conditions where SAR determination is impractical, field strength or power density measurements shall be carried out. In cases where SAR determination is appropriate, the values in Table 6 shall not be exceeded:

**Table 6
SAR Limits for Persons Not Classed As RF and Microwave Exposed Workers (Including the General Public)**

Condition	SAR Limit (W/kg)
The SAR averaged over the whole body mass	0.08
The local SAR for head, neck and trunk, averaged over any one gram (g) of tissue*	1.6
The SAR in the limbs, as averaged over 10 g of tissue*	4

* Defined as a tissue volume in the shape of a cube.

Although not a requirement of the Code, it is suggested that whenever possible, the organ-averaged SAR for the eye not exceed 0.2 W/kg. As stated in Appendix VII, this suggestion shall remain until sufficient scientific information is available to accurately assess the health effects of RF exposure on the eye.

2.2.3 Induced and Contact Current Limits

Limits for induced and contact currents exist to reduce the potential for RF shock or burns as follows:

(a) For free standing individuals (no contact with metallic objects), current induced in the human body by electromagnetic radiation in the frequency bands listed in Column 1 of Table 7 shall not exceed the value given in Column 2 of Table 7. Induced current measurements are described in Appendix V.

(b) No object, with which a person may come into contact by hand grip, shall be energized by electromagnetic radiation in the

frequency bands listed in Column 1 of Table 7 to such an extent that the current flow through an electrical circuit, having an impedance equivalent to that of the human body, exceeds the value given in Column 3 of Table 7, as measured with a contact current meter. Contact current measurements are described in Appendix V.

**Table 7
Induced and Contact Current Limits for Persons Not Classed as RF and Microwave Exposed Workers (Including the General Public)**

1 Frequency (MHz)	2 Rms Induced Current (mA) Through		3 Rms Contact Current (mA) Hand Grip and Through Each Foot	4 Averaging Time
	Both Feet	Each Foot		
0.003–0.1	900 <i>f</i>	450 <i>f</i>	450 <i>f</i>	1 s
0.1–110	90	45	45	0.1 h (6 min)

Notes: 1. Frequency, *f*, is in MHz.
2. The above limits may not adequately protect against startle reactions and burns caused by transient spark discharges for intermittent contact with energized objects.

(c) Where the electromagnetic radiation consists of a number of frequencies in the same or different frequency bands, shown in Column 1 of Table 7, the ratio of the square of the measured current at each frequency to the square of the limit at that given frequency shown in Column 2 or 3 (depending on whether it is the induced or contact current) shall be determined, and the sum of all ratios thus obtained for all frequencies shall not exceed unity when time averaged. See Section 2.1.3 for more details on calculating the sum.

(d) For frequencies between 3 kHz and 100 kHz, the averaging time to be applied to the induced and contact currents shall be 1 second(s). For frequencies between 100 kHz and 110 MHz, time averaging shall be applied to the square of the induced and contact currents and shall be consistent with the averaging time in Table 5 (0.1 h or 6 min), provided that the time-averaged square of the current in any 0.1 h (6 min) period does not exceed the limit given in the following:

$$I_{av}^2 = I_{lm}^2 \frac{6}{T_{exp}}$$

where I_{av} is the maximum allowable time-averaged current for exposure times less than 0.1 h (6 min), I_{lm} is the current limit through each foot (45 mA) as specified in Table 7, and T_{exp} is the exposure time in minutes during any 0.1 h (6 min) period. Shown in Table 8 are the higher values of I_{av} that may be allowed for exposure times less than 0.1 h (6 min).

Table 8
Time-Averaged Induced and Contact Current Limits for Different Exposure Times in the Frequency Band 0.1-110 MHz for Persons not classed as RF and Microwave Exposed Workers (Including the General Public)

Exposure Time (Min)	6-Minute, Time-Averaged Induced/Contact Current (rms) through Each Foot (mA)
6	45
5	49
4	55
3	64
2	78
1	110
0.5	155*

*Maximum instantaneous current for exposure times less than 0.5 min. is 155 mA.

Note: The above limits may not adequately protect against startle reactions and burns caused by transient spark discharges for intermittent contact with energized objects.

For exposure times less than 0.5 minutes, a maximum instantaneous current of 155 mA shall not be exceeded.

2.2.4 Peak Field Strength Limit for Pulsed Fields

For exposures to pulsed electromagnetic fields in the frequency range of 0.1 to 300 000 MHz, the peak value of the instantaneous field (temporal peak), in terms of electric field strength, shall not exceed 100 kV/m. For pulse duration less than 100 ms, and in the preceding frequency range, peak limits shall be derived using the formula given in Appendix IV. If the derived peak limits are greater than 100 kV/m, the exposure limit shall be taken as 100 kV/m.

2.3 Time Averaging

2.3.1 Frequency 0.003 MHz – 15 000 MHz

A single measurement is sufficient, unless the field is changing significantly (more than 20%) within a period of 0.1 h, in which case the time-averaged values must be calculated from multiple measurements. Some modern instruments have time-averaging capabilities. If this feature is not available on the instrument being used, the time-averaged values over 0.1 h can be obtained by using the following formulae:

(a) To obtain the time-averaged rms electric (E) or magnetic (H) field strength, use the applicable formula:

$$E = \left[\frac{1}{6} \sum_{i=1}^n E_i^2 \cdot \Delta t_i \right]^{1/2}$$

or

$$H = \left[\frac{1}{6} \sum_{i=1}^n H_i^2 \cdot \Delta t_i \right]^{1/2} ,$$

where E_i and H_i are the sampled rms electric and magnetic field strengths, respectively, which are considered to be constant in the i -th time period, Δt_i is the time duration, in minutes, of the i -th time period and n is the number of time periods within 6 min (0.1 h).

(b) To obtain the time-averaged power density W , use the formula

$$W = (1/6) \sum_{i=1}^n W_i \Delta t_i ,$$

where W_i is the sampled power density in the i -th time period.

(c) To obtain the time-averaged SAR, use the formula:

$$SAR = (1/6) \sum_{i=1}^n (SAR)_i \Delta t_i ,$$

where $(SAR)_i$ is the sampled SAR in the i -th time period.

Notes: (1) In all of the previous formulae, the following relationship shall be satisfied:

$$\sum_{i=1}^n \Delta t_i = 6 \text{ min},$$

(2) For pulsed fields, E_i and H_i are rms values, and W_i is the value averaged over the time interval Δt_i . If peak values are measured, the rms or average values shall be calculated.

2.3.2 Frequency 15 000 MHz – 300 000 MHz

In the frequency range 15 000 MHz–300 000 MHz, the averaging time, in minutes, shall be evaluated for field strengths using the formula:

$$\text{Averaging Time} = 616\,000 / f^{1.2},$$

where f is the frequency in MHz.

2.4 Measurements and Evaluation

2.4.1 Field Measurements – Spatial Averaging

Measurements to determine conformity with the limits specified in Sections 2.1.1 and 2.2.1 shall be performed with field sensors (probes) placed at least 0.2 m away from any object or person. To determine the spatially averaged value, local values including the maximum value shall be measured over a surface area of 0.35 m (width) x 1.25 m (height) perpendicular to the ground and at a reasonable distance (e.g., 0.5 m) above it. It is advisable that the measurement points are uniformly spaced within the sampling area. Local values should be measured in nine or more points. Where the field is reasonably uniform (within $\pm 20\%$), e.g., in the far-field, measurements suffice in one location, representative of the space that is occupied by a person. Appendix V may be consulted for more information on field measurements and spatial averaging. The spatially averaged values shall be calculated from the following formulae:

$$E = \left[\frac{1}{n} \sum_{i=1}^n E_i^2 \right]^{1/2},$$

$$H = \left[\frac{1}{n} \sum_{i=1}^n H_i^2 \right]^{1/2},$$

$$W = \frac{1}{n} \sum_{i=1}^n W_i,$$

where n is the number of locations, E_i , H_i and W_i are the electric field strength, the magnetic field strength and the power density, respectively, measured in the i -th location.

2.4.2 Determination

To satisfy the requirements of Sections 2.1.2 and 2.2.2, the SAR shall be determined with an uncertainty not greater than ± 25 percent. Any suitable and reliable computational or measurement method may be used. Appendix V may be consulted for more information.

2.4.3 Induced and Contact Current Measurements

Under certain conditions, the induced current can exceed the limits specified in Tables 3 and 7, even though the electric field strengths, which are the major contributor to the induced current, are below the limits specified in Tables 1 and 5^(8,9). These conditions may occur when the electric field strength is as low as 25% of the exposure limits.

For any conducting metallic object that a person may come in contact with and that is located in a high-intensity RF field, contact currents shall be measured. An electrical circuit having the impedance of the human body shall be used for measurements. Under certain conditions, the contact current can exceed the current limits specified in Tables 3 and 7, even though the electric field strengths, which are the major contributor to the contact current, are below the limits specified in Tables 1 and 5. These conditions may occur when the electric field strength is as low as 20% of the exposure limits shown in Tables 1 and 5. Appendix V may be consulted for more information.

3. Siting and Installation

3.1 Basic Principles

In order to institute protective measures in areas where RF devices are used, it is necessary to take into account the time workers may spend in these areas. When surveying around RF devices:

- (a) field levels shall be known in controlled areas where restricted occupancy is allowed. These areas shall be designated accordingly, and the maximum worker occupancy time shall be posted where applicable, and
- (b) exposure as well as induced and contact currents in uncontrolled areas shall not exceed the limits specified in Section 2.2.

3.2 General Recommendations

- (a) Warning signs, specified in Section 7.1, or suitable substitutes, indicating the presence of RF fields, shall be posted according to recommendations of Section 7.2 or 7.3.
- (b) The areas surrounding unmanned, high-power sources of RF radiation shall be fenced off to prevent unauthorized access to places where an overexposure could occur. If a metallic fence is used, the contact current limits specified in Tables 3 and 7 shall be met.
- (c) The siting of an RF device shall take into account the practical possibility of multiple source exposures from fields and leakage from other devices in the vicinity.
- (d) Metallic objects that are not necessary shall not be present near any radiating RF device, as they may cause high intensity fields in some locations.

3.3 RF and Microwave Heating Devices

RF and microwave heating devices are used to convert RF energy to heat. They may consist either of electrodes, coil(s) or antenna(s) which produce fields in the object to be heated as well as stray fields in the surrounding region. These devices have applications in the areas of scientific investigation, medical care and industrial processes. Examples of these devices are RF dielectric heaters and sealers for processing dielectric materials and short-wave and microwave diathermy equipment for therapeutic application. When such devices are used, the following recommendations apply:

- (a) Where radiated energy is directed into occupied areas, appropriate precautions shall be followed to ensure that exposure of people does not exceed the maximum levels specified in Section 2. Where the maximum level at the operator position exceeds those specified in Section 2, steps shall be taken, e.g., through the use of shielding, to bring unintended exposure levels to those specified in Section 2. Information about the shielding of RF dielectric heaters and sealers is given elsewhere⁽¹⁰⁾.
- (b) Where the fields produced by an RF and microwave heating device exceed the limits specified in Section 2.2 in locations accessible to persons not classified as RF and microwave exposed workers, there shall be an indicator that provides a visible warning when the RF power is on. Precautions shall be taken to ensure that when the RF power is on, no such persons are present in the locations where the limits are exceeded.

In evaluating operator exposures, it is advisable to measure induced body current in addition to electric and magnetic field measurements⁽¹⁰⁾.

3.4 Medical Devices and Electromagnetic Interference

It is advisable to use medical RF devices only in a room specifically designed, selected or modified to accommodate the patient and the device. Electromagnetic interference from devices such as short-wave diathermy and electrosurgical units may cause malfunctions, with potentially adverse consequences, to various medical devices, such as electrocardiographs, electromyographs, electroencephalographs, cardiac pacemakers, etc. Other sources of interference are radio, television and radar transmissions as well as mobile communications devices (e.g., cellular telephones, walkie-talkies and vehicle-mounted transceivers)⁽¹¹⁾. Electromagnetic interference can generally be eliminated by means of shielding, filtering or grounding of the spurious signals, or relocating the devices being affected. Pacemaker design has improved to the extent that its susceptibility to electromagnetic interference has been largely eliminated. Other medical devices are, or may be, designed to minimize the effects of electromagnetic interference. Information concerning RF electromagnetic interference with medical devices has been reported⁽¹²⁾.

3.5 Microwave Ovens

(a) Adjusting applied voltages, replacing the microwave power generating component, dismantling the components of the oven and refitting waveguides, shall be undertaken by persons specially trained for such assignments. The services of a qualified repair person should be sought when any malfunction is suspected.

(b) Special care is required to ensure that no damage occurs to the part of the oven making contact with the door or door seals.

(c) The power mains shall be disconnected before removing the oven outer shell.

(d) Before reaching into the rear compartment of the oven, the high voltage capacitors must be discharged in a safe manner.

(e) The door interlocks shall not be defeated⁽¹³⁾.

3.6 Radar and Communications Systems

(a) Wherever possible, the antenna beam shall be directed away from occupied areas. However, if the beam does irradiate occupied areas, the applicable maximum exposure limits given in Section 2 shall be observed. If needed, antenna sweep restrictions or RF power reduction may be employed to prevent the exposure limits from being exceeded in occupied locations.

(b) For any installation that is to be operated, all signs and barriers demarcating areas of restricted or denied occupancy and all interlock systems shall be permanently installed to prevent accidental access to the zone of denied occupancy.

3.7 Electroexplosive Devices

Care shall be taken to ensure that electroexplosive devices are not placed in RF fields of a level sufficient to cause serious risks. Firing circuitry along with the wires of electric blasting caps may, under certain circumstances, pick up sufficient energy from RF fields to cause caps to explode⁽¹⁴⁾. The susceptibility of the blasting caps to RF fields depends on the frequency, polarization and the strength of the field, and various factors in the design of the detonator – including to what extent it is electrically screened from radio interference. The level of field intensity that may prove hazardous depends on its frequency: the lower the frequency, the more susceptible are the detonators.

4. Safety Procedures for Operators and Maintenance Personnel of RF Devices (RF Workers)

(a) Maintenance personnel and operators of RF devices shall be aware of the potential hazards of RF fields.

(b) Particular care shall be taken to ensure that all people are clear of any direct beam of an RF device before it is switched on for test or maintenance purposes.

(c) Instructions and procedures for repair, maintenance and operation of a device, as specified by the manufacturer or a competent person, shall be readily available to, and be followed by, operators and maintenance personnel.

(d) Replacement components shall be equivalent to original components. Transmission lines, waveguides, gaskets, flanges and similar components shall have the same operating characteristics as the original components or be approved by the manufacturer of the original equipment, or a person trained in the safe use of this equipment.

(e) Testing of a device either before or after completion of any repair work shall be carried out after protective shields, waveguides and other components have been replaced in their designated locations.

(f) The correct operation of electronic test equipment and power meters shall be checked in advance, i.e., prior to using them at the repair station or test site.

(g) Adjustment of voltages, replacement of RF energy generating components, dismantling components or refitting transmission lines shall be undertaken by persons specially trained for such assignments. The services of a qualified repair person should be sought when any malfunction is suspected.

(h) The correct operation of all safety interlocks shall be tested and operators shall not defeat any safety interlock.

(i) An RF generating component shall be tested with an appropriate load connected to its output or with the radiated energy absorbed by anechoic material. The energy generated shall not be allowed to radiate freely into occupied areas.

5. Protection of the General Public

(a) Except under special circumstances, members of the general public shall not be allowed access to areas where levels exceed those specified in Section 2.2.

(b) Where access is possible, warning signs shall be posted at the entrance to any location containing RF devices capable of producing, under normal working conditions, levels that exceed those specified in Section 2.2.

(c) Any device capable of producing leakage that would result in levels close to those specified in Section 2.2 and to which unrestricted public access is allowed, shall be checked for conformity with existing applicable regulations after installation; when malfunction is suspected; and after any modification or repair that might cause leakage.

6. RF Surveys

6.1 RF Survey Procedures

The objective of a survey is to determine whether the device or installation complies with recommended standards of performance and personnel exposure, and to assess the effect of the location of the device with respect to controlled and uncontrolled areas in the environment. The following recommendations are made with respect to RF surveys:

- (a) RF surveys shall be carried out by competent persons.
- (b) Before routine operations begin, an RF survey shall be conducted for all new installations capable of producing levels exceeding those specified in Section 2.2.
- (c) A survey shall be made following any repairs, increases in radiated power or changes in working conditions, protective shielding and barriers that may increase the levels, to ensure that the levels do not exceed the limits specified in Section 2. This refers both to RF and microwave exposed workers and the general public.
- (d) A survey shall be conducted when any malfunction that may increase the field levels, induced body currents or contact currents is suspected.
- (e) A survey shall be conducted as frequently as practically possible around devices and at installations which are capable of producing fields, induced body currents or contact currents in excess of the limits set out in Section 2.
- (f) Survey instruments shall be selected to match the RF source and exposure conditions such as frequency, level of field strength or power density, near- or far-field. It is suggested that the measurement techniques specified in Appendix V be followed. Alternatively, other suitable techniques may be used^(15,16). Survey instruments shall be fully calibrated at least once every three years. Their performance should be checked against another calibrated instrument before carrying out a survey.
- (g) During a survey, a complete record of the field parameters (electric field strength, magnetic field strength or power density and induced body and contact currents) at each work site shall be kept to assist in making a realistic evaluation of compliance.

- (h) During the inspection of any RF device or installation, all safety interlocks and “ON-OFF” control switches shall be examined and placed in working order. The required warning signs, labels and tags must be readable and properly affixed to the device.

6.2 Records and Recommendations

(a) Records shall be kept of all RF survey measurements and their evaluation. The records shall include the date the measurements were made, number and type of devices in the area surveyed, the locations of measurement with respect to the RF emitting device, names and organization of who conducted the survey, survey results, as well as the model, serial number and calibration date of the measuring instrument(s) used. Other information that may prove useful would be photographs, floor plans, etc.

(b) Recommendations on appropriate changes in shielding, location and operation of the device, based on the evaluation of the survey measurements, shall be made to the person(s) responsible for the device. When a remedial action based on these recommendations has been taken, another survey should be made to verify the effectiveness of the actions.

7. Warning Signs

7.1 Design of the Recommended Warning Signs

Three warning signs described here are suggested for use. These signs or reasonable alternatives shall be used. The suggested signs are designed to indicate the nature and degree of hazard associated with a given device or location. The nature of the hazard is indicated by the symbol, and degree of hazard is indicated by the shape and colour of the sign. The warning signs and their meaning are given below. The size of the sign shall be appropriate to the conditions of use, such that it is clearly distinguishable, being either illuminated or employing reflective materials as necessary.

- The **CAUTION** sign is **BLACK** text and symbol on a **YELLOW** background.
- The **WARNING** sign is **BLACK** text and symbol on an **ORANGE** background.
- The **DANGER** sign is **RED** text and symbol on a **WHITE** background.

The **CAUTION** sign is not generally used for area demarcation, but it may be placed on devices to indicate that they produce RF fields. All RF devices for which regulations have been promulgated under the Radiation Emitting Devices Act have the **CAUTION** sign as part of their labelling requirements. For example, all microwave ovens complying with the Microwave Oven Regulations have the Caution sign attached. Both the **WARNING** and **DANGER** signs are used for identifying hazardous devices and for area demarcation.

7.2 Area Demarcation

(a) A **WARNING** sign shall be placed at the entrance of any zone within which a survey has shown that RF levels exceed those specified in Section 2.2 but are less than those specified in Section 2.1. The **WARNING** sign indicates that restricted occupancy is allowed

for RF and microwave exposed workers within its boundaries. It shall be located wherever it is necessary to indicate a recommended occupancy time. In such cases, the **WARNING** sign shall be accompanied by words such as “Warning Radiofrequency Radiation – Maximum Occupancy Time (t) Minutes” and the French equivalent, where t is determined according to the limits specified in Appendix II, taking into account 0.1 h averaging time.

(b) A **DANGER** sign shall be placed at the entrance of any zone where the field levels are in excess of those specified in Section 2.1. The **DANGER** sign thus indicates a **DENIED ACCESS** zone. When used for area demarcation, the **DANGER** sign shall be accompanied by words such as “Danger Radiofrequency Radiation – Do Not Enter” and the French equivalent.

(c) The signs shall be clearly visible and identifiable at all viewing distances where either significant exposures can occur or at the entrances to restricted area zones.

7.3 Signs for the Labelling of Devices

When the signs are used for labelling a device, the following recommendations apply:

(a) A **WARNING** sign shall be applied to any device, under development or in use for any industrial, scientific or medical purposes, if the device produces exposure levels that exceed those specified in Section 2.2 but are below those specified in Section 2.1. The **WARNING** sign shall be applied to a device if misuse or failure could cause RF radiation injury.

(b) A **DANGER** sign shall be applied to any device under development or in use for any industrial, scientific or medical purposes, if it produces exposure levels in excess of those specified in Section 2.1. Furthermore, even though exposure levels are below those specified in Section 2.1, the **DANGER** sign shall be applied if failure of the device could cause serious RF radiation injury or death.

AREA DEMARCATION



CAUTION

RADIOFREQUENCY RADIATION

- Area of Unrestricted Occupancy
- Minor Injury Possible from Misuse



WARNING

RADIOFREQUENCY RADIATION

- Area of Restricted Occupancy
(RF Workers Only)
- Serious Injury Possible from Misuse



DANGER

RADIOFREQUENCY RADIATION

- Area of Denied Occupancy
- Critical Injury or Death Possible

Archived

Appendix I Maximum Exposure Limits for RF Fields – Graphical Representation

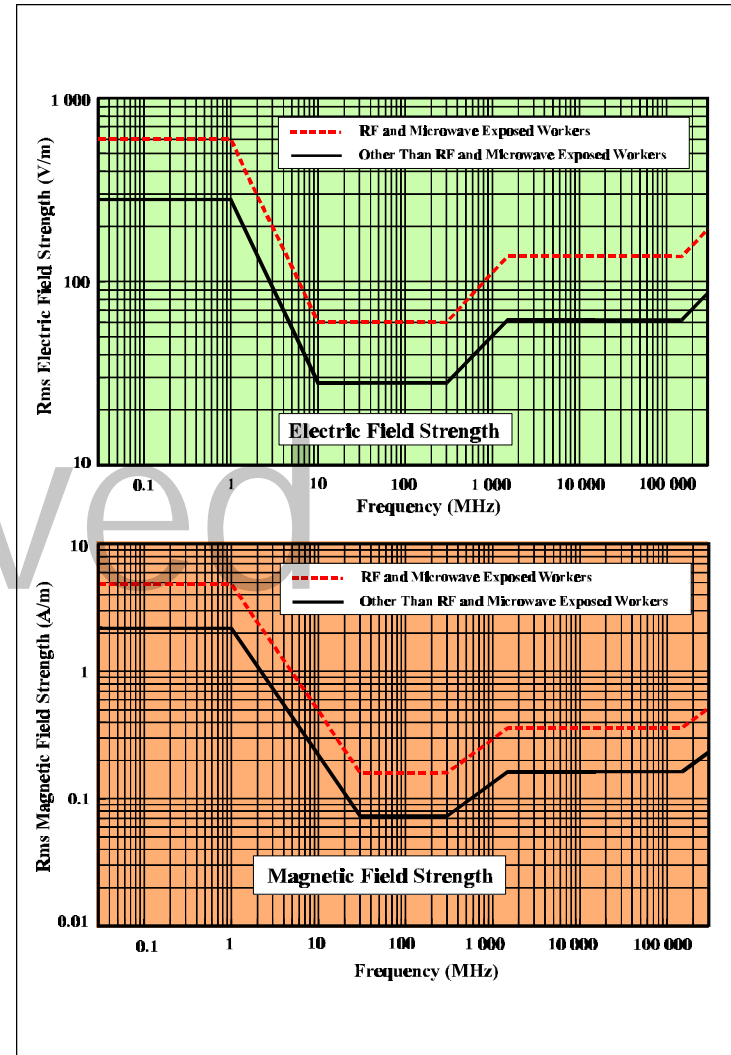


Figure I-1
Maximum Electric and Magnetic Field Strengths

Appendix II Maximum Exposure Duration for Time Periods Less Than 0.1 h and Frequencies Below 15 000 MHz

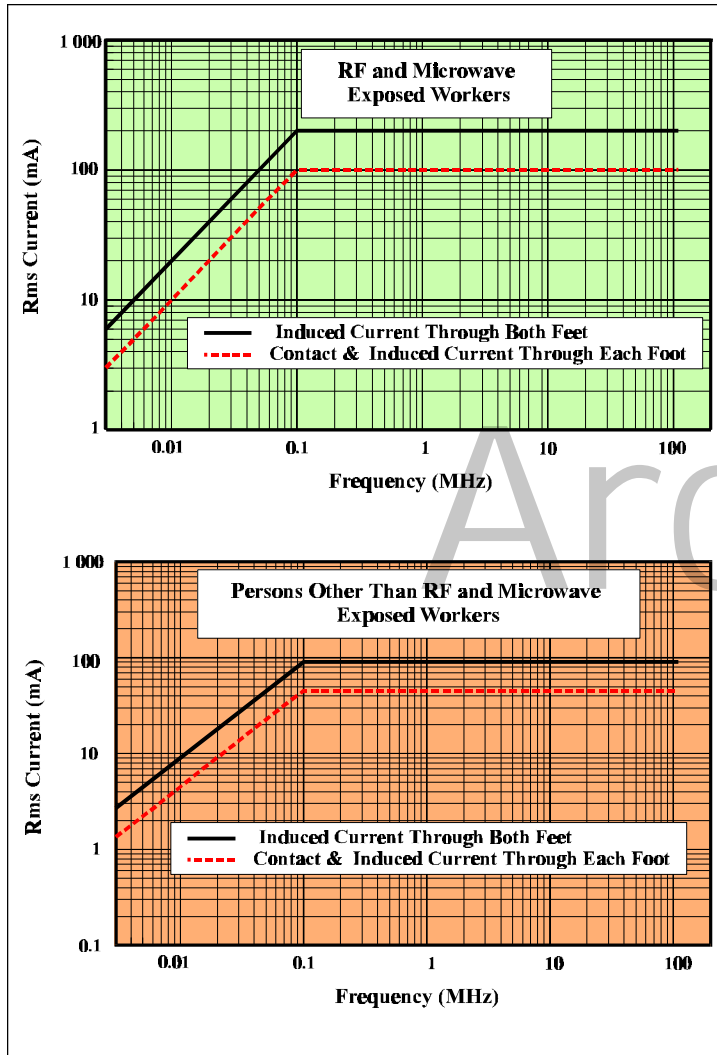


Figure I-2
Maximum Induced and Contact Currents

For exposure durations less than 0.1 h (6 min), higher exposure limits than those specified in Tables 1 and 5 are permitted. For the general public, this is not a very practical situation, as it is usually difficult to control how long a person can remain in a particular location where higher RF fields are present. However, it may be applied to devices operating in an intermittent manner, e.g., where RF power is on, for example, for 2 minutes every 10 minutes.

For RF workers, exposures to higher fields for short periods of time may be necessary for operational purposes. Exposure durations shall then be strictly controlled in order not to exceed the limits specified in Section 2.1.1. One minute is assumed here to be the shortest duration which is of practical importance.

Elevated exposures of electric and magnetic fields or power density are allowed for durations shorter than 0.1 h (6 min) as long as the equations in Section 2.3.1 apply.

Appendix III Theoretical Estimation of Exposure Fields

A. Near-Field and Far-Field Zones

Sources of RF electromagnetic fields may have widely different characteristics. For the purpose of evaluation of human exposure and protection against potentially harmful exposures, RF sources can be divided as follows:

- (a) small antennas; i.e., antennas whose dimensions are less than the wavelength (λ),
- (b) large antennas; i.e., antennas whose dimensions are greater than the wavelength, and
- (c) sources producing leakage (stray) fields, e.g., RF dielectric heaters, RF induction heaters, radar components.

The space around a source antenna is often divided into two zones: the near-field zone and the far-field zone (Figure III.1). The near-field zone can be further divided into two regions: the reactive near-field region and the radiating near-field region. The region of space immediately surrounding the antenna in which the induction (reactive) field exists is known as the reactive near-field region. Most electromagnetic energy in this region is not radiated but is stored. The near-fields vary rapidly with distance. At a short distance further away from the antenna, the reactive near-field is decreased significantly, and the radiating near-field predominates. In the radiating near-field region, the energy propagates away from the antenna, but the radiation still lacks a plane-wave character. Beyond the radiating near-field region is the far-field zone, in which the field strength varies inversely with distance from the antenna.

Small Antennas. An antenna whose greatest dimension is no greater than the wavelength of its recommended operating frequency is often referred to as a small antenna. Examples of small antennas are resonant dipoles, Yagi and log-periodic antennas. The reactive near-field region of these antennas extends up to a distance given below⁽³⁾

$$R_s = \lambda / 2\pi, \quad (\text{III.1})$$

where

R_s = extent of the reactive near-field region, in metres (m)

λ = wavelength, in metres (m).

For this type of antenna, there is no general formula for estimation of the field strength in the near-field zone. However, reasonable calculations can be made for some antennas (e.g., dipoles or monopoles). In general, for most small antennas, theoretical estimation of exposure in the near-field zone is difficult, and only measurements can provide a simple means of field evaluation.

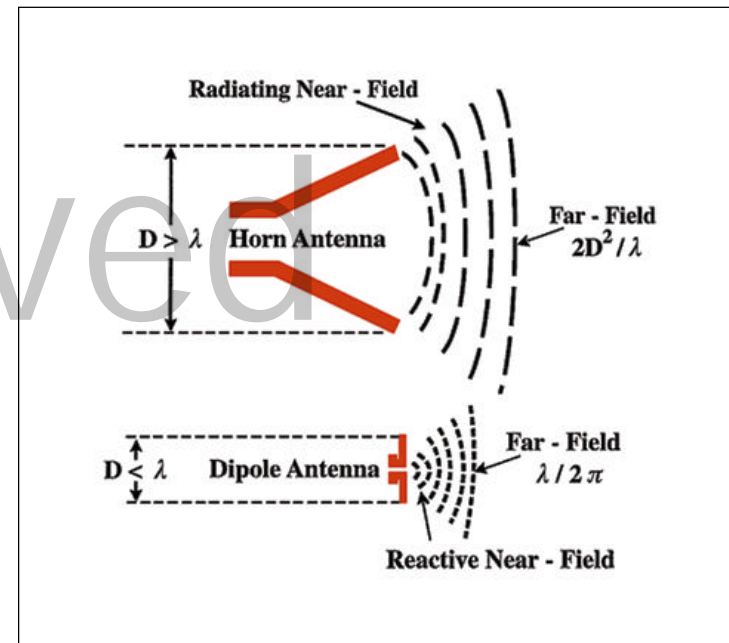


Figure III-1
Antenna size versus separation of the radiating near-field region, the reactive near-field region, and the far-field zone⁽³⁾.

Large Antennas. An antenna with its greatest dimension greater than the wavelength of its recommended operating frequency may be considered as a large antenna. Examples of large antennas are parabolic reflectors, arrays and horn antennas. The near-field zone of these antennas consists of the reactive region extending to the distance given by equation (III.1), followed by a radiating region. In the radiating near-field region, the field strength does not necessarily decrease with distance away from the antenna, but may exhibit an oscillatory character. More information on the field distribution in the radiating near-field region of aperture and reflector antennas can be found elsewhere^(15,17,18).

In much of the literature, the distance from the antenna to the far-field zone is taken to be $2D^2/\lambda$, where D is the greatest dimension of the antenna and λ is the wavelength. At this distance, the maximum phase difference of electromagnetic waves coming from different points on the antenna is 22.5 degrees⁽¹⁹⁾. In the case of radiation hazard assessment, however, a larger phase difference and thus a shorter distance marking the beginning of the far-field zone is acceptable. A realistic practical distance from a large antenna, e.g., a parabolic reflector, where the far-field zone begins is⁽³⁾

$$R_f = 0.5 D^2/\lambda, \quad (\text{III.2})$$

where

- R_f = distance which marks the beginning of the far-field region, in metres (m)
- D = the greatest dimension of the antenna, in metres (m)
- λ = wavelength, in metres (m).

For commonly used horn and reflector antennas, the maximum power density (within the antenna beam) for distances less than R_f (in the near-field zone) can be conservatively estimated as^(15, 17, 18)

$$W_m = 4P_T/A, \quad (\text{III.3})$$

where

- W_m = maximum power density, in watts per square metre (W/m^2)
- P_T = net power delivered to the antenna, in watts (W)
- A = physical aperture area, in square metres (m^2).

It should be noted that towards the end of the radiating near-field region and in the far-field zone, the electric and the magnetic fields are interrelated with each other and with the power density as follows:

$$E/H = \eta \quad (\text{III.4})$$

and

$$W = E^2/\eta = H^2\eta, \quad (\text{III.5})$$

where

- E = electric field strength, in volts per metre (V/m)
- H = magnetic field strength, in amperes per metre (A/m)
- W = power density, in watts per square metre (W/m^2)
- η = characteristic impedance (for free space $\eta = 377$ ohms).

In the far-field region, the power density (W) on the main beam axis can be calculated from the expression

$$\begin{aligned} W &= EIRP/(4\pi r^2) \\ &= P_T G/(4\pi r^2), \end{aligned} \quad (\text{III.6})$$

where

- $EIRP$ = effective isotropically radiated power, in watts (W)
- r = distance from the antenna, in metres (m)
- P_T = net power delivered to the antenna, in watts (W)
- G = antenna gain (power ratio) with respect to an isotropic antenna.

Equation (III.6) can be used to estimate W at distances greater than R_f (equation III.2)^(15,18). For distances just slightly greater than R_f , equation (III.6) gives an overestimate of W no greater than 0.8 dB or 20%⁽²⁰⁾.

The antenna gain is related to the antenna dimensions by the following equation⁽¹⁹⁾

$$G = 4\pi A_e/\lambda^2, \quad (\text{III.7})$$

where

- A_e = effective area of the antenna, $A_e = \epsilon A$
- A = physical aperture area of the antenna, in square metres (m^2)
- ϵ = antenna efficiency (typically $0.5 \leq \epsilon \leq 0.75$)
- λ = wavelength, in metres (m).

An electromagnetic wave can also be characterized by the electric field strength and magnetic field strength. The rms electric field strength at a distance r from a source with the $EIRP$ on the main beam axis, as derived from (III.5) and (III.6), is equal to

$$E = [30 EIRP]^{0.5}/r, \tag{III.8}$$

and is expressed in volts per metre (V/m).

Graphs relating power density and electric and magnetic field strengths in free space are shown in Figure III-2.

Equations (III.6) and (III.8) are used to determine the power density and field strength in the far-field region in a worst case condition where maximum power gain (Equation III.7) is applied. It should be noted that it is not always possible to predict the levels of maximum fields in and around sites of concern. This is due to the fact that RF fields may be absorbed, reflected and refracted by objects in a random and unpredictable manner. As such, the only way to determine actual levels of RF fields is by measurement.

Sources Producing Leakage Fields. For leakage radiation sources, there is no reliable method of estimation of the extent of the near-field zone, its type (whether reactive or radiating region) or the field strengths.

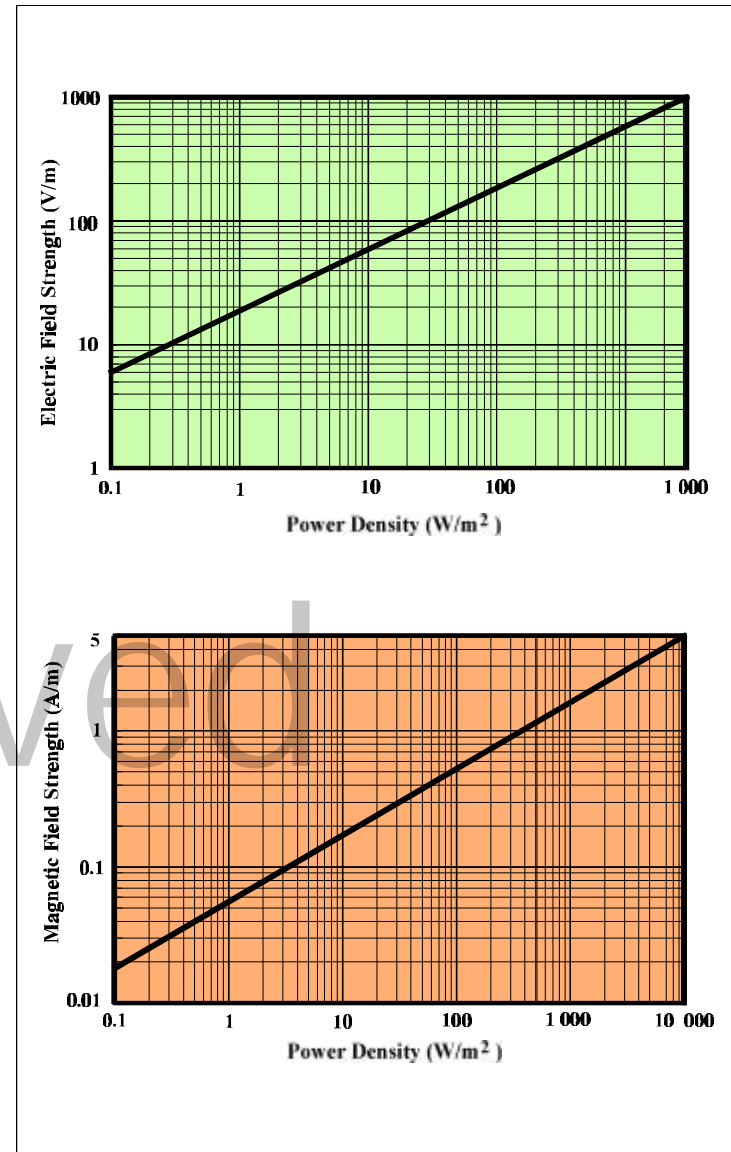


Figure III-2
Conversion Charts for Plane Wave ($10 \text{ W/m}^2 = 1 \text{ mW/cm}^2$)

Example III.1: Calculation of Minimum Distance Where Exposures Fall within the Limits.

A 0.5-m diameter parabolic antenna, operating at 1.20 GHz (1200 MHz) with an EIRP of 50 W is to be installed in an area accessible to the general public. What is the minimum distance from the antenna where the exposure does not exceed the limits for the general public?

1. Calculate the maximum power density exposure limit for the general public (Table 5):

$$\begin{aligned} W_{limit} &= f/150 \\ &= 1200/150 \\ &= 8 \text{ W/m}^2 \end{aligned}$$

2. Calculate the minimum distance by rearranging equation (III.6) to solve for the distance from the antenna r :

$$\begin{aligned} r_{min} &= [EIRP/(4\pi W_{limit})]^{0.5} \\ &= [50.0/(4.0 \times 3.14159 \times 8.0)]^{0.5} \\ &= 0.705 \text{ m} \end{aligned}$$

3. Check to make sure that the minimum distance calculated above is in the far-field zone (where equation III.6 is valid):

First calculate the wavelength:

$$\begin{aligned} \lambda &= 300/f \quad (f \text{ in MHz}) \\ &= 300/1200 \\ &= 0.25 \text{ m} \end{aligned}$$

As this antenna diameter is larger than the wavelength (λ), it may be considered as a large antenna. Thus, the beginning of the far-field region is calculated using equation (III.2) where in this case the parameter D is taken to be the diameter of the dish:

$$\begin{aligned} R_f &= 0.5 D^2 / \lambda \\ &= 0.5 \times (0.5)^2 / 0.25 \\ &= 0.5 \text{ m} \end{aligned}$$

Since the minimum distance, as calculated above, is in the far-field zone of the antenna, the basis for the calculation is valid. Therefore, members of the general public should not stand closer than 0.705 m directly in front of the antenna.

B. Average Power of Pulsed Waves

A pulse-modulated wave (pulsed wave) is shown in Figure III-3.

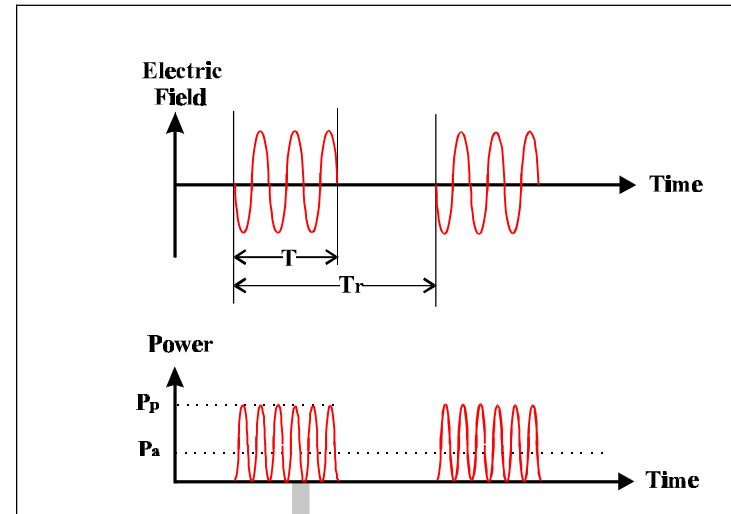


Figure III-3 Pulse-Modulated Field

This type of radiation is characteristic of radars.

The duty factor (F) can be calculated as

$$F = T/T_r, \tag{III.9}$$

where

T = pulse duration, in seconds (s)

T_r = time lapse between the start of consecutive pulses, in seconds (s).

The pulse repetition frequency is equal to

$$f_p = 1/T_r, \tag{III.10}$$

where

f_p = pulse repetition frequency, in hertz (Hz)

T_r = time lapse between the start of consecutive pulses, in seconds (s).

The average power P_a for a pulsed wave can be calculated as

$$P_a = P_p F, \quad (\text{III.11})$$

where

P_p = peak power, in watts (W)

F = duty factor.

Similarly for the average power density W_a

$$W_a = W_p F, \quad (\text{III.12})$$

where

W_p = peak power density, in watts per square metre (W/m^2)

F = duty factor.

C. Scanning Antennas

The effective power density as seen from a stationary point for a scanning antenna in motion can be estimated from the power density measured with the antenna stationary using the expression:

$$W_m = K W_s, \quad (\text{III.13})$$

where

W_m = effective power density for the antenna in motion, in watts per square metre (W/m^2)

K = antenna rotational reduction factor

W_s = power density measured on the main beam axis of the stationary antenna at a given distance, in watts per square metre (W/m^2).

The rotational reduction factor for the near-field region is equal to

$$K = a/R_\phi, \quad (\text{III.14})$$

where

a = the dimension of the antenna in the scan (rotation) plane, in metres (m).

$R_\phi = r\phi$ = the circumference of the antenna scan sector at the given distance (r), in metres (m), at which the measurements have been done (Figure III-4).

ϕ = scan angle, in radians.

The rotational reduction factor for the far-field region is

$$K = 3 \text{ dB beamwidth} / \text{scan angle} \quad (\text{III.15})$$

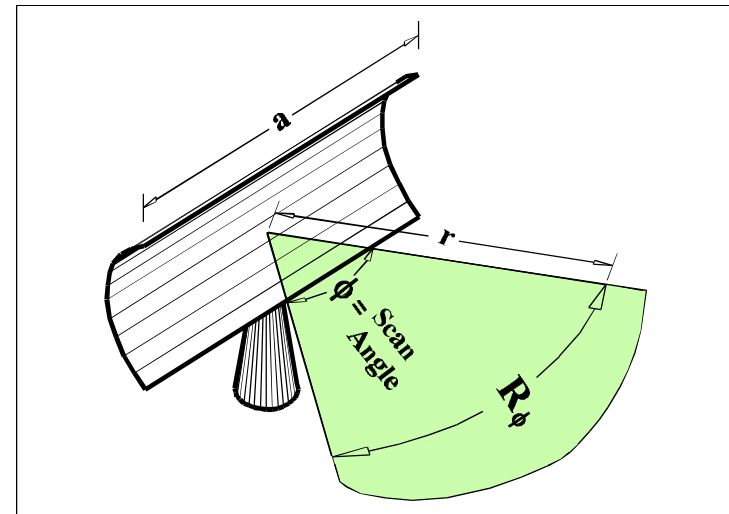


Figure III-4
Rotational Reduction Factor in the Near-Field

Example III.2:

Estimate the near-field maximum power density in front of the antenna of a radar system with the following characteristics:

Operating frequency (f): 10 GHz (gigahertz)

Transmitter peak power (P_p): 1 MW (megawatts)

Pulse duration (T): 3 μs (microseconds)

Pulse repetition frequency (f_p): 400 Hz

Antenna dimension (D): 5 m in diameter (parabolic dish)

Steps of calculation:

(i) The wavelength $\lambda = 300/f$ (f in MHz)
 $= 0.03 \text{ m}$

(ii) The distance where the far-field region begins
 $R_f = 0.5 D^2/\lambda = 417 \text{ m}$

(iii) The antenna physical aperture area $A = \pi D^2/4 = 19.63 \text{ m}^2$

(iv) The duty factor $F = T f_p = 1.2 \times 10^{-3}$

- (v) The average power $P_a = P_p F = 1.2$ kW.
This is the net power delivered to the antenna, P_T .
- (vi) The maximum power density (within the near-field region of the antenna beam)
 $W_m = 4P_T/A = 244.5$ W/m²

Exposure of a person in the near-field region should be avoided or limited to a short duration since the power density exceeds the limits (50 W/m² for RF and microwave exposed workers, 10 W/m² for the general public).

Example III.3:

Determine the effective power density at 10 m and 30 m from a scanning antenna in motion, given the following parameters:

Power density at 10 m with the antenna stationary:	100 W/m ²
Power density at 30 m with the antenna stationary:	20 W/m ²
The distance where the far-field region begins:	20 m
Antenna rotation (ϕ):	full (360° or 2π radians)
Antenna aperture dimensions (a, b):	2 m wide, 10.16 cm high
Antenna beamwidths:	1.23° horizontal, 25° vertical

Calculation:

- (i) The 10 m location is in the near-field region. At this location,
The circumference of the antenna scan $R_\phi = 2\pi \times 10$ m
The rotational reduction factor $K = a/R_\phi = 2/(2\pi \times 10) = 0.1/\pi$
The effective power density when the antenna is in scanning mode
 $W_m = KW_s = (0.1/\pi)(100) = 3.2$ W/m²
- (ii) The rotational reduction factor is different, since the 30 m location is in the far-field.
 $K = 3$ dB beamwidth / scan angle = $1.23^\circ/360^\circ$
The effective power density when the antenna is in scanning mode
 $W_m = KW_s = (1.23/360)(20) = 0.07$ W/m²

Appendix IV Limits of Exposure to Pulsed RF Fields

- While the average power density of pulsed waves shall be within the limits specified in Tables 1 and 5, the peak value of the instantaneous electric field strength (temporal peak) of the wave shall not exceed 100 kV/m (Sections 2.1.4 and 2.2.4). Calculation of the average power density is discussed in Appendix III.B.
- For exposures to pulsed RF fields of pulse durations less than 100 milliseconds (ms) and frequencies in the range of 0.1 MHz to 300 000 MHz, the exposure limit in terms of peak power density for a single pulse is based on limiting the energy density of a single pulse according to:
 - Energy density of a single pulse must be no greater than one-fifth of the maximum allowable energy density in a 0.1 h time period. In mathematical terms, this is given by⁽⁵⁾

$$W_p = \frac{W_L T_a}{5 T}$$

where

- W_p = peak power density exposure limit for a single pulse, in W/m²
 W_L = continuous wave exposure limit as specified in Table 1 or 5, in W/m²
 T = pulse duration as defined in Appendix III.B, in seconds
 T_a = averaging time as specified in Table 1 or 5, in seconds.
 A maximum of five such pulses is permitted during any period equal to the averaging time.
- b. If there are more than 5 pulses during any period equal to the averaging time, or if the pulse durations are greater than 100 ms, normal time averaging applies, except that the energy density delivered during any 100 ms period is limited by the formula

$$\sum W_p T = \frac{W_L T_a}{5}$$

Appendix V Measurements and Evaluation

A. RF Fields

The area around any RF source is generally divided into two zones: the near-field zone, and the far-field zone. More information on this subject can be found in Appendix III and references^(15,18,21). In many RF safety surveys, the exposure levels have to be determined in the near-field zone of the source. Not infrequently, the field comprises RF radiation from several sources. Difficulties can be encountered in determining field strengths and power density of such fields, as outlined in references^(15,21), and special care should be devoted to the selection of a survey instrument. Only instruments that are designed for operation in the frequency range required shall be used.

A.1 Basic Characteristics of Survey Meters

In surveying fields in the near-field zone of an antenna or in close proximity to a device, both electric field and magnetic field strengths shall be measured where possible. However, instrumentation for the measurement of magnetic fields at certain frequencies may not be commercially available. In this case, the electric field strength shall be measured. In the far-field zone, it is sufficient to measure any of the following parameters: electric field strength, magnetic field strength or power density. Many meters have indicators that are calibrated in power density units (e.g., mW/cm²), but the quantity actually measured may be the square of the strength of the electric or magnetic field. It must be remembered that power density measurements in the near-field zone are not meaningful for the evaluation of exposure levels. The information about the measured field parameter is normally provided in the instruction manual.

If the frequency range covered by one survey instrument is narrower than the frequency range of the fields generated by the RF sources in the vicinity of the site surveyed, as many instruments as necessary shall be used to determine the fields in the whole range of frequencies.

Since, in the majority of RF surveys, the orientation(s) of the electromagnetic field vector is not known, a survey meter having an isotropic detecting element is preferred.

If the only meter available is one having a single-axis detecting element, measurements of the total field can be performed by employing three mutually perpendicular orientations of the detecting element and calculating the resultant field from the following equations:

$$E = [E_1^2 + E_2^2 + E_3^2]^{1/2} \quad (\text{V.1})$$

or

$$H = [H_1^2 + H_2^2 + H_3^2]^{1/2} \quad (\text{V.2})$$

or

$$W = W_1 + W_2 + W_3, \quad (\text{V.3})$$

where the subscripts 1, 2 and 3 refer to measurements in the three mutually orthogonal orientations.

In performing survey measurements in the near-field of an RF source, a meter suitable for operation in the near-field shall be employed. Special care is required to avoid perturbing the field by the instrument (e.g., the meter casing, but not the field probe), and by other objects or people in the vicinity.

When amplitude or frequency modulated and especially pulsed fields are surveyed, the meter response to such fields shall be evaluated to determine if it is capable of measuring these types of fields.

A survey instrument shall be calibrated against a standard every three years and its operation checked at least once a year or after any repair that may affect its operation.

Exposure levels in the vicinity of RF sources having scanning (rotating) antennas may have to be determined with the antenna stationary, because of the limitations of the available measuring instruments. The exposure conditions when the antenna is in motion are then evaluated using methods described in Appendix III (Section C). More detailed information about measurements of potentially hazardous RF fields can be found in references^(15,16,18,21).

A.2 Spatial Averaging

In conducting RF field surveys, locations accessible to people where maximum field strengths exist are identified. Even in the far-field of an RF radiator, the field strengths may vary over the cross-sectional (projected) area of a human body (approximately 0.6 m²) because of ground reflections and scattering from nearby objects. As a result, spatial averaging is required in most cases.

Frequently, exposure is in the near-field or in close proximity to reflecting objects where the fields are spatially non-uniform. A method for performing a spatially averaged measurement is as follows:

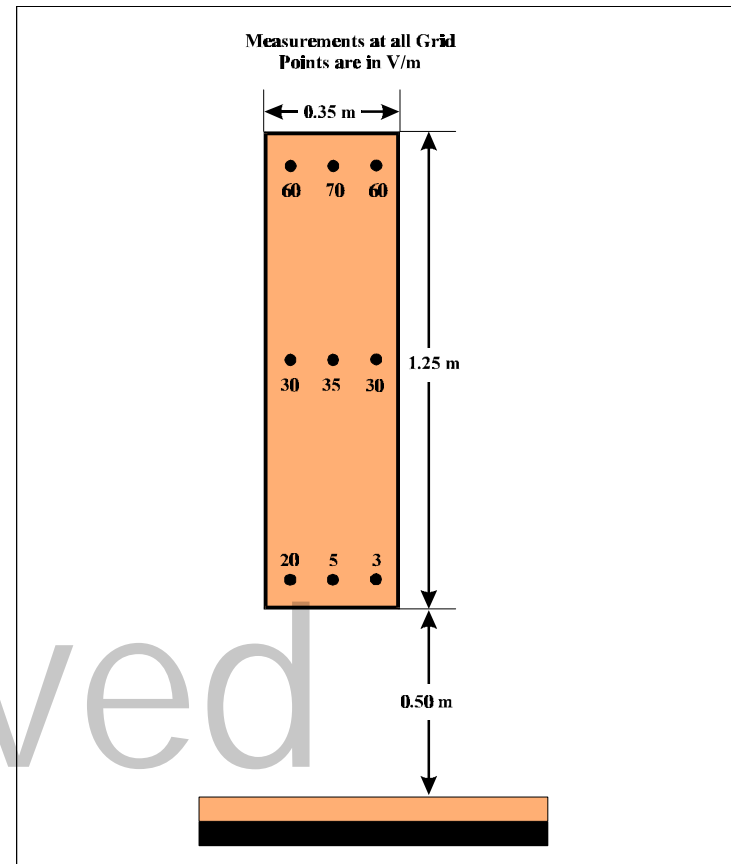
- (a) determine the location of the maximum field.
- (b) establish around the location of the maximum field a grid of points within approximately 0.35 m (width) x 1.25 m (height) surface area, at a reasonable distance (e.g., 0.5 m) above the floor or ground and perpendicular to it. These points should be uniformly spaced within the grid with the point of the maximum field included.
- (c) measure the field strength in all points of the grid.
- (d) calculate the average field.

Note: A person performing measurements shall approach the exposure source from afar to avoid overexposure. In questionable situations, measurements may be performed with the output power of the source reduced, or the person may gradually approach the source while monitoring the field.

The average field strength along a grid of n points may be calculated from the equation

$$F = \frac{1}{\sqrt{n}} \left[\sum_{i=1}^n F_i^2 \right]^{1/2},$$

where F_i is the rms field strength measured at the point i . An example of a measurement grid for the spatial averaging is given in Figure V-1.



$$E = (1/\sqrt{9}) [20^2 + 5^2 + 3^2 + 30^2 + 35^2 + 30^2 + 60^2 + 70^2 + 60^2]^{1/2} = 41.6 \text{ V/m}$$

Figure V-1
Example of a Grid for Measurements of a Non-Uniform Electric Field of 27 MHz and the Calculation of the Average Field

B. Specific Absorption Rate (SAR)

A very careful and well documented assessment of SARs has to be performed for conformity with the requirements of Sections 2.1.2 and 2.2.2. It should be remembered that the internal field within a human body, and thus the SAR, are not related to the external field in a simple way.

Determination of SARs for near-field exposures of humans is difficult and can be done only on simulated models of the human body under laboratory conditions. Both computational methods and measurements are feasible. To be valid, they have to be reliable and reasonably accurate.

There are two general approaches in computational methods⁽²²⁾. One involves the use of an analytical technique for calculation of distribution of absorbed energy in simplified tissue geometries such as plane slabs, cylinders and spheroids. The other uses a numerical formulation for analysing the coupling of radiofrequency energy to human bodies. Examples of numerical methods for SAR calculations are the impedance method, the method of moments and the finite-difference time domain (FDTD) technique. Detailed representations of the complex geometry and composition of the human body have been made available using data from computerized tomography and magnetic resonance imaging scans. Recent advances in computers (memory and speed) and in the FDTD technique have led to the development of a tool for analysis of SAR in the human head from various cellular telephones^(23,24,25). This numerical tool allows a detailed modelling of anatomically relevant human inhomogeneities, such as those in the head, that are difficult to model experimentally. Software for numerical calculation of local and regional SARs is commercially available, but at the time of writing, there is not enough information to discuss the calculation accuracy.

Measurement methods have been developed for determination of SAR in experimental animals and models made of tissue-equivalent synthetic material^(26,27). Such simulated models are referred to as phantoms. Measurement methods are used to verify the accuracy of numerical calculations. There are two basic methods for SAR measurements. One is to use a temperature probe to measure the temperature change caused by the heat produced by the absorbed RF energy, and then calculate SAR from⁽¹⁵⁾

$$SAR = c \frac{\Delta T}{\Delta t} ,$$

where ΔT is the temperature rise (in °C) within the time interval Δt (in seconds), and c is the tissue (or phantom material) specific heat capacity, in J/kg°C. Calculations of SARs from temperature rise can be done only if the temperature rise is linear with time. This method is appropriate for local SAR measurement when the exposure levels (irradiating fields) are intense enough so that the temperature rise is not influenced significantly by heat transfer within and out of the body.

The second basic method for SAR determination is to measure the electric field inside the body with implantable electric field probes and then calculate the SAR from

$$SAR = \sigma E^2 / \rho ,$$

where σ is the tissue conductivity (S/m), E is the rms electric field strength induced in the tissue (V/m) and ρ is the mass density (kg/m³). This method is suitable only for measuring SAR at specific points in the body and for low values of SAR where the absorbed energy is insufficient to cause a detectable change in temperature. Instrumentation for this type of SAR measurement method usually includes an implantable electric field probe, a phantom and a computer controlled system for positioning the probe^(28,29). This instrumentation has recently become commercially available and has been used to test portable transmitters for compliance.

More information about various methods of SAR determination can be found in references^(15,21,30-34). New methods may become available after publication of this document.

C. Contact and Induced Currents

C.1 Contact Current

An RF field induces an alternating electric potential on ungrounded or poorly grounded conducting (metallic) objects such as cars, trucks, buses, cranes and fences. When a person touches such objects, RF current flows through the person to ground (Figure V-2). The amount of the current depends on the object (its size, shape), the frequency and strength of the field and the person's impedance. The impedance in turn depends on the person's height, weight and body composition (ratio of the lean to fat body mass), type of contact (surface area of contact, i.e., finger or grasp, skin wet or dry), and the type of footwear. The impedance also varies with the frequency of the RF field.

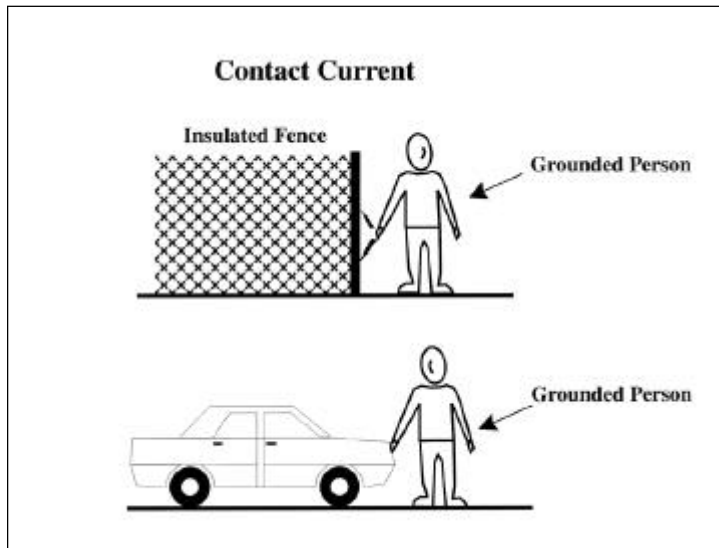


Figure V-2
Typical Situations Where Currents Can Be Perceived by Persons
Touching Ungrounded or Poorly Grounded Conducting Objects

Contact current flowing through the person is perceived at a certain level; at a higher level it becomes painful and at a still higher level may cause an injury (e.g., local burn, respiratory tetanus, heart effects). Below a frequency of about 100 kHz the perception is of a tingling, prickling feeling in the finger or hand touching the object. At higher frequencies heat is perceived. Thresholds for perception and pain under various conditions have been measured and more information can be found in references^(35, 36).

Currents below the limits set in Section 2.1.3 (Table 3) for RF and microwave exposed workers will not cause pain, but may be perceived. Since females are more sensitive^(35,36), the lower percentile (more sensitive) was selected for setting the limits. Currents below the limits set in Section 2.2.3 (Table 7) will not be perceived. In this case extrapolated data for children were used^(35, 36).

Contact currents are evaluated using an electronic circuit representing the impedance of the average human body in grasp contact with an insulated, conductive object, energized by an RF field. More information about the equivalent human impedance can be found elsewhere^(37, 38).

An evaluation for compliance with the limits for contact currents (Tables 3 and 7) should be made with an appropriate instrument. Contact current meters are commercially available.

C.2 Induced Current

Even though a person may not be touching a metallic object, RF currents which are induced in the body by RF fields may flow through the body to ground.

Induced current through both feet can be measured by using a clamp-on current probe or a low profile platform consisting of two parallel conductive plates isolated from each other and one located above the other. If the latter is used, the platform is placed on the surface where the person stands, and a person or a human equivalent antenna is placed on the upper plate of the platform. A voltage drop on a low-inductance resistor placed between the plates provides a measure of the induced current.

An evaluation for compliance with the limits of induced currents should be made with an appropriate instrument. A person or a human equivalent antenna should stand upright on the platform of the induced current meter. Induced current meters and human equivalent antennas are commercially available.

Appendix VI X-Radiation

In general, high power systems utilizing high-voltage transmitting or other high-power tubes (greater than about 20 kV) have potential to emit x-radiation. Because high power RF devices often require high operating voltages, it is considered appropriate to include in this Safety Code a few pertinent details regarding x-radiation safety. When the manufacturer's data or other observations indicate that a device may generate x-radiation, the following procedures and exposure limits are recommended:

(a) The RF power generating component shall be inspected to determine if specified x-radiation shields are in their designated locations.

(b) With the shields correctly positioned on the device, a survey shall be conducted to ensure that the x-radiation exposure does not exceed 0.5 mR (milliroentgen) in an hour at 5 cm from any accessible external surface of the device ($0.5 \text{ mR} = 129 \text{ nC/kg}$). The survey shall be conducted by personnel knowledgeable in measurements of x-radiation and in interpreting the results.

(c) Survey instruments used for the measurement of x-radiation intensity shall not be susceptible to RF radiation. See references⁽³⁹⁻⁴¹⁾.

(d) Survey procedures, reports and records shall be similar to those applied in Radiation Surveys as specified in Sections 6.1 and 6.2.

Appendix VII Rationale for Changes to the 1991 Version of Safety Code 6

1. Portable Transmitters and Exemption Clause

These devices are normally used in close proximity to the human body (within 2.5 cm), and therefore direct measurements of electric and magnetic fields do not give a reliable exposure level. In the 1991 version of Safety Code 6, portable transmitters operating below 1 GHz with radiated power of 7 W were exempt from compliance with the SAR requirements specified in Sections 2.1 and 2.2, regardless of the distance.

Recent scientific information⁽⁴²⁾ indicates that certain devices (e.g., cellular telephones), which were previously exempt, produced exposures in excess of the SAR limits specified in Section 2.2. Thus, the exemption clause stated in the previous Safety Code 6 has been removed.

2. Time Averaging

The time factor of 0.1 h (6 min) may be considered as a thermal time constant. An exposure time of 0.1 h or longer will allow such mechanisms as heat conduction, blood circulation and thermoregulation to influence the temperature rise in a given body region⁽⁴³⁾.

At frequencies above approximately 15 000 MHz, the time period over which exposure is averaged needs to be reduced to prevent skin burns. As the frequency increases, the power from RF fields is deposited within an increasingly thin layer of skin and subcutaneous tissue. The new limits bring the maximum allowed level at 300 000 MHz (wavelength 1 mm) into agreement with that specified in the ANSI laser standard at the same frequency⁽⁴⁴⁾, in accordance with the CENELEC proposal⁽⁴⁵⁾. Since at frequencies above 15 000 MHz all power is superficially deposited in the human body,

considerations used in the derivation of exposure limits at lower frequencies (see Section 2) become less relevant. At the same time, skin burns become the limiting factor for both occupational as well as other exposures.

The 0.1 h time period over which exposure is averaged is not valid for the case of induced and contact currents at frequencies lower than about 100 kHz, where RF shock or burn may be possible. For the purpose of determining compliance with the limits specified in Sections 2.1.3 and 2.2.3, the currents should be measured with an instrument having an averaging time no greater than 1 second.

3. Peak Field Strength Limit

The electric field limit of 100 kV/m for single and multiple pulses is recommended for prevention of air breakdown and spark discharges. Additional clauses with respect to pulsed RF fields, similar to those in IEEE Std C95.1-1991 – 1999 Edition, have been added in Appendix III. The rationale for these clauses refers to auditory effects and energy-induced unconsciousness in rats. The basis for this limit is to reduce the energy absorption for each of the pulses to 20% of the energy absorption allowed under continuous wave exposures.

4. Contact Current Limits

The revised limits in this Code provide the same health and safety protection as the previous limits. The differences in numerical values reflect a different protocol for measurements in the establishment of conformity to the Code. These revised limits are identical to those in the IEEE Std C95.1-1991 – 1999 Edition standard. The selection of a specific formulation of the clauses and test procedures in the ANSI standard have resulted in the development of commercial instruments suitable for conformity testing. The circuits recommended in Appendix IV Part C of the previous Safety Code 6 have not been produced commercially and, therefore, are removed from this document. Instead, the clauses and test procedures in IEEE Std C95.1-1991 – 1999 Edition are recommended to facilitate conformity evaluation.

5. Induced Current Limits

Currents which are induced in the body by RF fields may flow through the body to ground. These limits have therefore been introduced in order to minimize shocks and burns due to RF field exposure, even though the measured fields are within the exposure limits specified in Sections 2.1.1 and 2.2.1⁽⁸⁾.

The perception of currents at frequencies lower than 70-100 kHz is quite different than that from currents at higher frequencies. While the perception is one of tingling or pricking sensation at frequencies lower than about 100 kHz, the sensory perception is that of warmth at the higher frequencies⁽⁴⁶⁾. Different current averaging times are, therefore, suggested for the induced and contact current limits given in Tables 3 and 7.

6. SAR Limits

In the 1991 version of Safety Code 6, Section 2.1.2, the limit for the SAR at the body surface and in the limbs (averaged over 10 g of tissue) was 25 W/kg. In response to the latest scientific information^(4,5), the limit has been reduced to 20 W/kg. Also in the 1991 version of Safety Code 6, the power density limits for the general public were set at one-fifth of the values for RF and microwave exposed workers. For the sake of consistency, the SAR limits for the general public (Section 2.2.2) have been adjusted to one-fifth of the values given in Section 2.1.2.

The SAR limits for the eye, specified in the 1991 version of Safety Code 6, were based on the experimental data reported by Kues *et al.*⁽⁴⁷⁾. This report described that ocular exposure of anesthetized primates to 100 W/m² pulsed fields at 2.45 GHz (*SAR* = 2.6 W/kg) and 200 W/m² continuous-wave field (*SAR* = 6.3 W/kg) for 4 h/d resulted in endothelial cell damage in the primate corneas. Although the changes appeared reversible, some endothelial cell loss was reported. Further investigations by Kues *et al.*⁽⁴⁸⁾ indicated that 2.45-GHz pulsed microwaves, if administered after pretreatment with ophthalmic drugs, could produce ocular effects at a significantly lower SAR level. However, Kamimura *et al.*⁽⁴⁹⁾ reported that ocular exposure of anesthetized primates to 300 W/m² continuous-wave field at 2.45 GHz did not result in ocular abnormalities. Since these studies have not been independently replicated and no further research has been conducted in this area, it is considered scientifically unjustified to continue imposing SAR limits for the eye based on such

limited information. However, the authors of this document consider these limited findings sufficient to encourage the reduction of ocular exposures whenever possible. This recommendation shall remain valid until sufficient scientific information is available to accurately assess the health effects of RF exposure on the eye.

7. Field Strength Limits

In Tables 1 and 4, the coefficients used in determining the maximum field strength limits between 300 MHz and 1500 MHz have been slightly adjusted in order to satisfy equation III.5.

8. 3-kHz Low Frequency Boundary

The low frequency portion of this Code has been extended to 3 kHz to cover the entire very-low-frequency (VLF) band. At the time of writing, information on the health effects of electromagnetic fields at frequencies below 3 kHz was insufficient to establish exposure limits.

The rationale for any parts or sections of this Code that remain unchanged from the 1991 version is given elsewhere⁽¹⁾.

Appendix VIII Definitions

Antenna – A device for radiating or receiving radiofrequency (RF) energy.

Antenna Gain – The increase in power transmitted or received by a directional antenna when compared to a standard antenna, which is usually an ideal isotropic antenna. Gain is a ratio of powers and may be expressed in decibels (dB) or as a pure number.

Auditory Effect – Human perception to individual pulses from RF fields in the form of audible clicks, chirping or buzzing sounds, depending on the pulsing regime and intensity of the field⁽³⁾.

Cavity – The interior of a metal structure that encloses or confines a radiofrequency field.

Computerized Tomography – A diagnostic-imaging procedure in which anatomical information is digitally reconstructed from x-radiation transmission data obtained by scanning an anatomical area from many directions.

Competent Person – An individual who because of his/her knowledge, training and experience is qualified to carry out RF and microwave surveys and/or repair and maintain RF and microwave devices.

Contact Current – Current flowing between an energized, isolated, conductive (metal) object and ground through an electrical circuit representing the equivalent impedance of the human body.

Continuous Wave (CW) – Successive oscillations which are identical under steady-state conditions (an unmodulated electromagnetic wave).

Controlled Environment (area) – A 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 results of transient passage through areas where analysis shows the exposure level may be

above those shown in Table 5 but do not exceed those in Table 1 and where the induced currents may exceed the values in Table 7 but do not exceed the values in Table 3.

Denied Access Area – An area not to be accessed by any person.

Duty Factor – The ratio of the pulse duration to the pulse period (i.e., time lapse between the start of consecutive pulses) of a periodic pulse train. Mathematically, the duty factor is the product of the pulse duration multiplied by the pulse repetition frequency.

Effective Isotropically Radiated Power (EIRP) – This term applies to directional antennas. The power that would have to be transmitted by an isotropic antenna to produce the same power density at any given point along the directional antenna's axis. Mathematically, EIRP is the gain of a transmitting antenna multiplied by the net power delivered to the antenna from the connected transmitter.

Electric Field – The region surrounding an electric charge, in which the magnitude and direction of the force on a hypothetical test charge is defined at any point.

Electrical Ground – The earth or a metal surface placed in contact with the earth, or connected to the earth with a conductor.

Electromagnetic Interference – Degradation of the performance of a device, a piece of equipment, or a system caused by an electromagnetic disturbance.

Electromagnetic Radiation – The propagation of time-varying electric and magnetic fields through space at the velocity of light.

Extremities – Limbs of the body, including upper arms and thighs.

Far-Field Zone – The space beyond an imaginary boundary around an antenna. The boundary marks the beginning where the angular field distribution is essentially independent of the distance from the antenna. In this zone, the field has a predominantly plane-wave character.

Field Strength – The magnitude of the electric or magnetic field, normally a root-mean-square value.

Frequency – The number of sinusoidal cycles made by electromagnetic waves in one second; usually expressed in units of hertz (Hz).

General Public – All persons not employed as RF and microwave exposed workers or those not working in controlled environments (areas). They include pregnant women, the aged, children, the chronically ill and disabled.

Induced Current – Current induced in a human body exposed to RF fields.

Interlock – A component or set of components that, when actuated, prevents the generation of power from an RF and microwave source, such as the magnetron in a microwave oven or an RF transmitter.

Leakage Radiation – Any unintended or accidental radiation emitted by a device outside its external surface.

Magnetic Field – A region of space surrounding a moving charge (e.g., in a conductor) being defined at any point by the force that would be experienced by another hypothetical moving charge. A magnetic field exerts a force on charged particles only if they are in motion, and charged particles produce magnetic fields only when they are in motion.

Magnetic Resonance Imaging – A technique for obtaining images of the internal anatomy based on the use of nuclear magnetic resonance (NMR) signals. The NMR method is based on partially aligning the nuclear spins by use of strong, static magnetic field, stimulating these spins with an RF field oscillating at the precession frequency of nuclear magnetic moments, and detecting the signal that is induced at this frequency.

Microwave – A radio wave which has a frequency of between 1 GHz and 300 GHz or a wavelength of between 30 cm and 1 mm.

Modulated Wave (radiation) – An electromagnetic wave which is modified by pulsing, or by varying its amplitude, frequency or phase. Such a wave is called, respectively, pulse-, amplitude-, frequency-, or phase-modulated.

Near-Field Zone – A volume of space generally close 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 zone is further subdivided into the *reactive near-field region* and the *radiating near-field region*.

Occupationally Exposed Persons – Workers who are exposed to RF fields and microwaves in the course of their regular employment.

Organ-averaged SAR for the eye – *Specific Absorption Rate (SAR)* averaged throughout the whole eye ball.

Owner – A person, organization or institution having title to, or, an administrative control over a given RF emitting device.

Plane Wave Character – Nature of the angular field distribution in the far-field region of a source antenna, in which the electric field vector is perpendicular to the magnetic field vector, and they are both perpendicular to the direction of propagation.

Power Density – The rate of flow of electromagnetic energy per unit surface area usually expressed in W/m² or mW/cm² or μW/cm².

Portable Transmitter – A mobile device that radiates electromagnetic waves for the purpose of communication, examples of which are cellular telephones and walkie-talkies.

Radiofrequency – The frequency in the portion of the electromagnetic spectrum that is between 3 kHz and 300 GHz.

Radiation (electromagnetic) – The emission or transfer of energy through space in the form of electromagnetic waves.

Radiating Near-Field Region – The region between the reactive near-field and the far-field wherein the radiation field dominates the reactive field, but lacks substantial plane-wave character.

Reactive Near-Field Region – The region that is closest to an antenna or other radiating structure and contains most or nearly all of the stored energy.

Responsible User – A person who is authorized to operate an RF device properly and safely with respect to RF radiation.

Restricted Occupancy – An area where access is restricted to RF and microwave exposed workers for a prescribed time duration.

RF Device – A device which generates and/or utilizes RF energy.

RF Survey – An evaluation of the actual or potential RF field levels in any area, specifically in the vicinity of RF devices, and an evaluation of induced and contact currents.

RF Worker – An employee or a person (including a pregnant woman) who because of his/her knowledge, training and experience with RF devices is qualified to work with these devices properly and safely with respect to RF exposure.

RF and Microwave Exposed Workers – Persons who are exposed to RF fields and microwaves in the course of their daily work (e.g., those who may work near an RF device but may not be RF workers).

rms – Root mean square. Mathematically, it is the square root of the average of the square of the instantaneous field or current taken throughout one period.

Safety – The absence of detrimental health effects from RF exposures.

Safety Officer – A person who is appointed to ensure safety of working within an RF environment.

Specific Absorption Rate (SAR) – The rate of radiofrequency energy absorbed in tissue per unit mass. Quantitatively, it is the time derivative (rate) of the incremental energy (dW) absorbed by an incremental mass (dm) contained in a volume element (dV) of given mass 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). Also

$$SAR = \sigma E^2 / \rho$$

where σ is the tissue conductivity (S/m), E is the rms electric field strength induced in the tissue (V/m) and ρ is the mass density (kg/m³).

SI – An acronym of *Système International d'Unités* (International System of Units).

Transceiver – A combination of transmitter and receiver in a single housing, with some components being used by both parts.

Uncontrolled Area – Any area that is neither a Restricted Occupancy Area, nor a Denied Access Area.

Visible Warning Indicator – A display such as flashing lights and signs to warn people of the fact that the power of an RF device is on.

Wavelength – The distance travelled by a propagating wave in one cycle of oscillation.

X-Radiation – Electromagnetic radiation having a wavelength in the range of 0.0001 to less than 1 nm.

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