

IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz

Sponsor

IEEE Standards Coordinating Committee 28 on Non-Ionizing Radiation Hazards

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Abstract: IEEE C95.1-1991 gives recommendations to prevent harmful effects in human beings exposed to electromagnetic fields in the frequency range from 3 kHz to 300 GHz. The recommendations are intended to apply to exposures in controlled, as well as uncontrolled, environments. They are not intended to apply to the purposeful exposure of patients by or under the direction of practitioners of the healing arts. The recommendations at 300 GHz are compatible with existing recommendations of safe exposure in the infrared frequency range (starting at 300 GHz). A rationale that describes how the recommendations were arrived at, and the factors taken into account in formulating them, is included.

Keywords: Electromagnetic fields, exposure limits, microwave, MPE, non-ionizing radiation, radiation protection, RFPG, radio frequency, safety levels

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This second printing incorporates minor typographical corrections to the original printed text.

Foreword

(This Foreword is not a part of IEEE C95.1-1991, IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz.)

In 1960, the American Standards Association approved the initiation of the Radiation Hazards Standards project under the co-sponsorship of the Department of the Navy and the Institute of Electrical and Electronics Engineers.

Prior to 1988, C95 standards were developed by an accredited standards committee C95, and submitted to ANSI for approval and issuance as ANSI C95 standards. Between 1988 and 1990, the committee was converted to Standards Coordinating Committee 28 Under the sponsorship of the IEEE Standards Board. In accordance with policies of the IEEE, C95 standards will be issued and developed as IEEE standards, as well as being submitted to ANSI for recognition.

The present scope of IEEE SCC28 is:

“Development of standards for the safe use of electromagnetic energy in the range of 0 Hz to 300 GHz relative to the potential hazards of exposure of man, volatile materials, and explosive devices to such energy. It is not intended to include infrared, visible, ultraviolet, or ionizing radiation. The committee will coordinate with other committees whose scopes are contiguous with SCC28.”

The IEEE Standards Coordinating Committee 28 is responsible for the present revision. There are five subcommittees concerned with:

- I Techniques, Procedures, and Instrumentation
- II Terminology and Units of Measurements
- III Safety Levels with Respect to Human Exposure, 0–3 kHz
- IV Safety Levels with Respect to Human Exposure, 3 kHz–300 GHz
- V Safety Levels with Respect to Electro-Explosive Devices

Three standards, one guide and two recommended practices have been issued. Current versions are:

IEEE C95.1-1991, IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz. (Replaces ANSI C95.1-1082.)

ANSI C95.2-1981, American National Standard Radio Frequency Radiation Hazard Warning Symbol. Reaffirmed in 1989.

ANSI C95.3-1973, IEEE Standard Techniques and Instrumentation for the Measurement of Potentially Hazardous Electromagnetic Radiation at Microwave Frequencies. Reaffirmed in 1979.

IEEE C95.3-1991, IEEE Standard Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields—RF and Microwave. (Replaces ANSI C95.3-1973 and

ANSI C95.4-1978, American National Standard Safety Guide for the Prevention of Radio-Frequency Radiation Hazards in the Use of Electric Blasting Caps.

ANSI C95.5-1981, American National Standard Recommended Practice for the Measurement of Hazardous Electromagnetic Fields—RF and Microwave.

Changes in the latest revision include an expanded frequency range, limits on induced body current to prevent radio-frequency (RF) shock or burn, a relaxation of limits on exposure to magnetic fields at low frequencies, and exposure limits and averaging time at high frequencies that are compatible at 300 GHz with existing infrared maximum-permissible exposure (MPE) limits. Important improvements in rules for valid measurement of electromagnetic fields have been introduced, and expanded rules for relaxing the exposure limits for the case of partial body exposure have been developed. Also, a distinction is made between controlled and uncontrolled environments relative to safe exposure limits.

This standard prescribes MPEs to prevent biological injury from exposure to electromagnetic radiation. Revisions of the original version of this standard (ANSI C95.1-1966) were made in 1974 and major revisions of ANSI C95.1-1974 were made in 1982 to take into account the significant expansion of the data base, improvements in dosimetry, and the increasing number of people in the general population exposed to RF fields. The changes in the standard included a wider frequency coverage, frequency dependence resulting from the recognition of whole-body resonance and incorporation of dosimetry. In addition to those changes, the present standard also includes a distinction between controlled and uncontrolled environments and guidelines for partial-body and near-field exposures. Exposure limits in the uncontrolled environment are lower than in the controlled environment under certain conditions, such as resonance, or when exposure is complicated by associated hazards like RF shock or burn.

This standard contains a detailed discussion of both the rationale and the limitations of the recommended guidelines based on the present data base.

This standard was prepared by the Subcommittee IV on Safety Levels with Respect to Human Exposure, 3 kHz to 300 GHz, of IEEE Standards Coordinating Committee 28, and had the following membership at the time this standard was prepared:

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IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz

1. Scope and Purpose

Recommendations are made to prevent harmful effects in human beings exposed to electromagnetic fields in the frequency range from 3 kHz to 300 GHz. These recommendations are intended to apply to exposures in controlled, as well as uncontrolled, environments. These recommendations are not intended to apply to the purposeful exposure of patients by or under the direction of practitioners of the healing arts. The recommendations at 300 GHz are compatible with existing recommendations on safe exposure in the infrared frequency range (starting at 300 GHz). See [B2].

2. Definitions and Glossary of Terms

average (temporal) power (P_{avg}): The time-averaged rate of energy transfer

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

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

$$MPE' = MPE \left[\frac{T_{avg}}{T_{exp}} \right]$$

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

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

controlled environment: Controlled environments are locations where there is exposure that may be incurred by persons who are aware of the potential for exposure as a concomitant of employment, by other cognizant persons, or as the incidental result of transient passage through areas where analysis shows the exposure levels may be above those

shown in Table 2 but do not exceed those in Table 1, and where the induced currents may exceed the values in Table 2, Part B, but do not exceed the values in Table 1, Part B.¹

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

electric field strength (E): A field vector quantity that represents the force (**F**) on a positive test charge (*q*) at a point divided by the charge.

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

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

energy density (electromagnetic field): The electromagnetic energy contained in an infinitesimal volume divided by that volume.

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

exposure, partial-body: Partial-body exposure results when RF fields are substantially nonuniform over the body. Fields that are nonuniform over volumes comparable to the human body may occur due to highly directional sources, standing-waves, re-radiating sources or in the near field. See **RF “hot spot.”**

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

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

magnetic field strength (H): A field vector that is equal to the magnetic flux density divided by the permeability of the medium. Magnetic field strength is expressed in units of amperes per meter (A/m).

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

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

Magnetic flux density is expressed in units of tesla (T). One T is equal to 10⁴ gauss (G).

maximum permissible exposure (MPE): The rms and peak electric and magnetic field strengths, their squares, or the plane-wave equivalent power densities associated with these fields and the induced and contact currents to which a person may be exposed without harmful effect and with an acceptable safety factor.

mixed frequency fields: The superposition of two or more electromagnetic fields of differing frequency.

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

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

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

¹The means for the identification of these areas is at the discretion of the operator of a source.

power density, average (temporal): The instantaneous power density integrated over a source repetition period.

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

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

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

power density, peak: The maximum instantaneous power density occurring when power is transmitted.

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

pulse modulated field: An electromagnetic field produced by the amplitude modulation of a continuous wave carrier by one or more pulses.

radio frequency (RF): Although the RF spectrum is formally defined in terms of frequency as extending from 0 to 3000 GHz, for purposes of this standard, the frequency range of interest is 3 kHz to 300 GHz.

re-radiated field: An electromagnetic field resulting from currents induced in a secondary, predominantly conducting, object by electromagnetic waves incident on that object from one or more primary radiating structures or antennas. Re-radiated fields are sometimes called “reflected” or more correctly “scattered fields.” The scattering object is sometimes called a “re-radiator” or “secondary radiator.” See **scattered radiation**.

RF “hot spot.”: A highly localized area of relatively more intense radio-frequency radiation that manifests itself in two principal ways:

- 1) The presence of intense electric or magnetic fields immediately adjacent to conductive objects that are immersed in lower intensity ambient fields (often referred to as re-radiation), and
- 2) Localized areas, not necessarily immediately close to conductive objects, in which there exists a concentration of radio-frequency fields caused by reflections and/or narrow beams produced by high-gain radiating antennas or other highly directional sources. In both cases, the fields are characterized by very rapid changes in field strength with distance. RF hot spots are normally associated with very nonuniform exposure of the body (partial body exposure). This is *not* to be confused with an actual thermal hot spot within the absorbing body.

root-mean-square (rms): The effective value, or the value associated with joule heating, of a periodic electromagnetic wave. The rms value is obtained by taking the square root of the mean of the squared value of a function.

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

short-term exposure: Exposure for durations less than the corresponding averaging time.

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

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

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

specific absorption rate (SAR): The time derivative of the incremental energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume element (dV) of given density (ρ).

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

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

uncontrolled environment: Uncontrolled environments are locations where there is the exposure of individuals who have no knowledge or control of their exposure. The exposures may occur in living quarters or workplaces where there are no expectations that the exposure levels may exceed those shown in Table 2 and where the induced currents do not exceed those in Table 2, Part B. Transitory exposures are treated in 4.1.1.

wavelength (λ): The wavelength (λ) of an electromagnetic wave is related to the frequency (f) and velocity (v) by the expression $v = f\lambda$. In free space the velocity of an electromagnetic wave is equal to the speed of light, i.e., approximately 3×10^8 m/s.

3. References

This standard shall be used in conjunction with the following documents:

[1] IEEE C95.3-1991, IEEE Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields—RF and Microwave.²

[2] IEEE Std 100-1988, IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI).

4. Recommendations

4.1 Maximum Permissible Exposure (MPE)

4.1.1 MPE in Controlled Environments

For human exposure in controlled environments to electromagnetic energy at radio frequencies from 3 kHz to 800 GHz, the MPE, in terms of rms electric (E) and magnetic (H) field strengths, the equivalent plane-wave free-space power densities (S) and the induced currents (I) in the body that can be associated with exposure to such fields or contact with objects exposed to such fields, is given in Table 1 as a function of frequency. Exposure associated with a controlled environment includes: exposure that may be incurred by persons who are aware of the potential for exposure as a concomitant of employment, exposure of other cognizant individuals, or exposure that is the incidental result of passage through areas where analysis shows the exposure levels may be above those shown in Table 2, but do not exceed those in Table 1, and where the induced currents may exceed the values in Table 2, Part B, but do not exceed the values in Table 1, Part B.³

²IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854-1331, U.S.A.

³The means for the identification of these areas is at the discretion of the operator of a source.

Table 1—Maximum Permissible Exposure for Controlled Environments

Part A				
Electromagnetic Fields*				
1	2	3	4	5
Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) E-Field, H-Field (mW/cm²)	Averaging Time E ², H ² or S (minutes)
0.003–0.1	614	163	(100, 1 000 000)†	6
0.1–3.0	614	16.3/ <i>f</i>	(100, 10 000/ <i>f</i> ²)†	6
3–30	1842/ <i>f</i>	16.3/ <i>f</i>	(900/ <i>f</i> ² , 10 000/ <i>f</i> ²)†	6
30–100	61.4	16.3/ <i>f</i>	(1.0, 10 000/ <i>f</i> ²)†	6
100–300	61.4	0.163	1.0	6
300–3 000			<i>f</i> /300	6
3 000–15 000			10	6
15 000–300 000			10	616 000/ <i>f</i> ^{1.2}

Part B			
Induced and Contact Radio Frequency Currents"‡			
Frequency Range	Maximum Current (mA)		Contact
	Through both feet	Through each foot	
0.003–0.1 MHz	2 000 <i>f</i>	1 000 <i>f</i>	1 000 <i>f</i>
0.1–100 MHz	200	100	100

f=frequency in MHz

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

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

‡It should be noted that the current limits given above may not adequately protect against startle reactions and burns caused by transient discharges when contacting an energized object. See text for additional comment.

- a) In a controlled environment, access should be restricted to limit the rms RF body current (averaged over any 1 second) and potential for RF shock or burn as follows:
 - i) For freestanding individuals (no contact with metallic objects), RF current induced in the human body, as measured through each foot, should not exceed the following values:
 - I = 1000*f* mA for (0.003 < *f* ≤ 0.1 MHz)
 - I = 100 mA for (0.1 < *f* < 100 MHz)

- ii) For conditions of possible contact with metallic bodies, maximum RF current through an impedance equivalent to that of the human body for conditions of grasping contact [see 4.3 (1)], as measured with a contact current meter, shall not exceed the following values:
 $I = 1000f \text{ mA for } (0.003 < f \leq 0.1 \text{ MHz})$
 $I = 100 \text{ mA for } (0.1 < f < 100 \text{ MHz})$
- b) The MPEs refer to exposure values obtained by spatially averaging over an area equivalent to the vertical cross-section of the human body (projected area). In the case of partial-body exposure, the MPEs can be relaxed as described in 4.4. In nonuniform fields, spatial peak values of field strengths may exceed the MPEs if the spatially averaged value remains within the specified limits. The MPEs may also be relaxed by reference to SAR limits in 4.2.1 by appropriate calculations or measurements.
- c) The MPE refers to values averaged over any 6-minute period for frequencies less than 15 GHz and over shorter periods for higher frequencies down to 10 s at 300 GHz, as indicated in Table 1.
- d) For near-field exposures at frequencies less than 300 MHz, the applicable MPE is in terms of rms electric and magnetic field strength, as given in Table 1, columns 2 and 3. For convenience, the MPE may be expressed as equivalent plane-wave power density, given in Table 1, column 4.
- e) For mixed or broadband fields at a number of frequencies for which there are different values of the MPE, the fraction of the MPE [in terms of E^2 , H^2 , or power density (S)] incurred within each frequency interval should be determined and the sum of all such fractions should not exceed unity. See Appendix C for an example of how this is accomplished.
 In a similar manner, for mixed or broadband induced currents at a number of frequencies for which there are different values of the MPE, the fraction of the induced current limits (in terms of I^2) incurred within each frequency interval should be determined, and the sum of all such fractions should not exceed unity.
- f) For exposures to pulsed radio frequency fields, in the range of 0.1 to 300 000 MHz, the peak (temporal) value of the MPE in terms of E field is 100 kV/m.
- g) For exposures to pulsed radio frequency fields of pulse durations less than 100 milliseconds and frequencies in the range of 0.1 to 300 000 MHz, the MPE, in terms of peak power density for a single pulse, is given by the MPE (Table 1, E-field equivalent power density) multiplied by the averaging time in seconds and divided by 5 times the pulse width in seconds. That is:

$$\text{Peak MPE} = \frac{\text{MPE} \times \text{Avg Time (seconds)}}{5 \times \text{Pulse width (seconds)}} \quad (1)$$

A maximum of five such pulses, with a pulse-repetition period of at least 100 ms, is permitted during any period equal to the averaging time [see 4.1.1(c)]. If there are more than five pulses during any period equal to the averaging time, or if the pulse durations are greater than 100 ms, normal averaging-time calculations apply, except that during any 100 ms period, the energy density is limited per the above formula, viz

$$\Sigma \text{ Peak MPE} \times \text{Pulsewidth (seconds)} = \frac{\text{MPE} \times \text{Avg. Time (seconds)}}{5}$$

4.1.2 MPE in Uncontrolled Environments

For human exposure in uncontrolled environments to electromagnetic energy at radio frequencies from 3 kHz to 300 GHz, the MPE, in terms of rms electric (E) and magnetic (H) field strengths, the equivalent plane-wave free-space power densities (S) and the induced currents (I) in the body that can be associated with exposure to such fields or contact with objects exposed to such fields are given in Table 2 as a function of frequency.

Exposure associated with an uncontrolled environment is the exposure of individuals who have no knowledge or control of their exposure. The exposure may occur in living quarters or workplaces where there are no expectations that the exposure levels may exceed those shown in Table 2, and where the induced currents do not exceed those in Table 2, Part B. Transitory exposures are treated in 4.1.1.

Table 2—Maximum Permissible Exposure for Uncontrolled Environments

Part A					
Electromagnetic Fields*					
1	2	3	4	5	
Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) E-Field, H-Field (mW/cm²)	Averaging Time E ², S or H ² (minutes)	
0.003–0.1	614	163	(100, 1 000 000)†	6	6
0.1–1.34	614	16.3/ <i>f</i>	(100, 10 000/ <i>f</i> ²)†	6	6
1.34–3.0	823.8/ <i>f</i>	16.3/ <i>f</i>	(180/ <i>f</i> ² , 10 000/ <i>f</i> ²)†	<i>f</i> ² /0.3	6
3.0–30	823.8/ <i>f</i>	16.3/ <i>f</i>	(180/ <i>f</i> ² , 10 000/ <i>f</i> ²)†	30	6
30–100	27.5	158.3/ <i>f</i> ^{1.668}	(0.2, 940 000/ <i>f</i> ^{3.336})†	30	0.0636/ <i>f</i> ^{1.337}
100–300	27.5	0.0729	0.2	30	30
300–3 000			<i>f</i> /1 500	30	
3 000–15 000			<i>f</i> /1 500	90 000/ <i>f</i>	
15 000–300 000			10	616 000/ <i>f</i> ^{1.2}	

Part B			
Induced and Contact Radio Frequency Currents‡"			
Frequency Range	Maximum Current (mA)		Contact
	Through both feet	Through each foot	
0.003–0.1 MHz	900 <i>f</i>	450 <i>f</i>	450 <i>f</i>
0.1–100 MHz	90	45	45

f=frequency in MHz

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

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

‡It should be noted that the current limits given above may not adequately protect against startle reactions caused by transient discharges when contacting an energized object. See text for additional comment.

- a) In uncontrolled environments, where individuals unfamiliar with the phenomenon of induced RF currents may have access, it is recommended that precautions be taken to limit induced currents to values not normally perceptible to individuals, as well as to prevent the possibility of RF burns.
- i) For freestanding individuals (no contact with metallic bodies), RF current induced in the human body, as measured through each foot, should not exceed the following values:
- I* = 450 *f* mA for (0.003 < *f* ≤ 0.1 MHz)
- I* = 45 mA for (0.1 < *f* < 100 MHz)

- ii) For conditions of possible contact with metallic bodies, maximum RF current through an impedance equivalent to that of the human body for conditions of grasping contact [see 4.3(1)], as measured with a contact current meter, shall not exceed the following values:

$$I = 450f \text{ mA for } (0.003 < f \leq 0.1 \text{ MHz})$$

$$I = 45 \text{ mA for } (0.1 < f < 100 \text{ MHz})$$

- b) The MPEs refer to exposure values obtained by spatially averaging over an area equivalent to the vertical cross-section of the human body (projected area). In the case of partial-body exposure, the limits can be relaxed, as described in 4.4. In nonuniform fields, spatial peak values of field strengths may exceed the MPEs if the spatial average value remains within the specified limits. The MPEs may also be relaxed by reference to SAR limits in 4.2.1 by appropriate calculation or measurement.
- c) The MPE refers to values averaged over any 6-min to 30-min period for frequencies up to 3 000 MHz, and over shorter periods for higher frequencies, down to 10 s at 300 GHz, as indicated in Table 2.
- d) For near-field exposures at frequencies less than 300 MHz, the applicable MPE is in terms of rms electric and magnetic field strength, as given in Table 2, columns 2 and 3. For convenience, the MPE may be expressed as equivalent plane-wave power density, given in Table 2, column 4.
- e) For mixed or broadband fields at a number of frequencies for which there are different values of the MPE, the fraction of the MPE [in terms of E^2 , H^2 , or power density (S)] incurred within each frequency interval should be determined, and the sum of all such fractions should not exceed unity. See Appendix C for an example of how this is accomplished.
In a similar manner, for mixed or broadband induced currents at a number of frequencies for which there are different values of the MPE, the fraction of the induced current limits (in terms of I^2) incurred within each frequency interval should be determined, and the sum of all such fractions should not exceed unity.
- f) For exposures to pulsed radio frequency fields in the range of 0.1 to 300 000 MHz, the peak (temporal) value of the MPE, in terms of E field, is 100 kV/m.
- g) For exposures to pulsed radio frequency fields of pulse durations less than 100 ms, and frequencies in the range of 0.1 to 300 000 MHz, the MPE, in terms of peak power density for a single pulse, is given by the MPE (Table 2, E-field equivalent power density), multiplied by the averaging time in seconds, and divided by 5 times the pulse width in seconds. That is:

$$\text{Peak MPE} = \frac{\text{MPE} \times \text{Avg Time(seconds)}}{5 \times \text{Pulsewidth(seconds)}} \quad (2)$$

A maximum of five such pulses, with a pulse-repetition period of at least 100 ms, is permitted during any period equal to the averaging time [see 4.1.2(c)]. If there are more than five pulses during any period equal to the averaging time, or if the pulse durations are greater than 100 ms, normal averaging-time calculations apply, except that during any 100 ms period, the energy density is limited per the above formula, viz

$$\Sigma \text{ Peak MPE} \times \text{Pulsewidth(seconds)} = \frac{\text{MPE} \times \text{Avg. Time (seconds)}}{5}$$

4.2 Exclusions

4.2.1 Controlled Environment

At frequencies between 100 kHz and 6 GHz, the MPE in controlled environments for electromagnetic field strengths may be exceeded if:

- a) the exposure conditions can be shown by appropriate techniques to produce SARs below 0.4 W/kg as averaged over the whole-body and spatial peak SAR, not exceeding 8 W/kg as averaged over any 1 g of tissue (defined as a tissue volume in the shape of a cube), except for the hands, wrists, feet and ankles where the spatial peak SAR shall not exceed 20 W/kg, as averaged over any 10 g of tissue (defined as a tissue volume in the shape of a cube), and
- b) the induced currents in the body conform with the MPE in Table 1, Part B.

The SARs are averaged over any 6-min interval. Above 6 GHz, the relaxation of the MPE under partial body exposure conditions is permitted (see 4.4).

At frequencies between 0.003 and 0.1 MHz the SAR exclusion rule, stated above, does not apply. However, the MPE in controlled environments can still be exceeded if it can be shown that the peak rms current density, as averaged over any 1 cm^2 area of tissue and 1 s does not exceed $35f \text{ mA/cm}^2$, where f is the frequency in MHz.

4.2.1.1 Low-Power Devices: Controlled Environment

This exclusion, consistent with the provision of 4.2.1, pertains to devices that emit RF energy under the control of an aware user. This exclusion addresses exposure of the user. For such devices, the exposure of other persons in the immediate vicinity of the user will meet the exclusion criterion for the uncontrolled environment. (See 4.2.2.)

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

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

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

4.2.2 Uncontrolled Environments

At frequencies between 100 kHz and 6 GHz, the MPE in uncontrolled environments for electromagnetic field strengths may be exceeded if:

- a) The exposure conditions can be shown by appropriate techniques to produce SARs below 0.08 W/kg, as averaged over the whole body, and spatial peak SAR values not exceeding 1.6 W/kg, as averaged over any 1 g of tissue (defined as a tissue volume in the shape of a cube), except for the hands, wrists, feet and ankles where the spatial peak SAR shall not exceed 4 W/kg, as averaged over any 10 g of tissue (defined as a tissue volume in the shape of a cube), and
- b) The induced currents in the body conform with the MPE in Table 2, Part B.

The averaging time for SARs is as indicated in Table 2. Above 6 GHz, the relaxation of the MPE under partial body exposure conditions is permitted (See 4.4).

At frequencies between 0.003 and 0.1 MHz, the SAR exclusion rule does not apply. However, the MPE in uncontrolled environments can still be exceeded if it can be shown that the peak rms current density, as averaged over any 1 cm^2 area of tissue and 1 s, does not exceed $15.7f \text{ mA/cm}^2$, where f is the frequency in MHz.

4.2.2.1 Low-Power Devices: Uncontrolled Environment

This exclusion, consistent with the provisions of 4.2.2, pertains to devices that emit RF energy without control or knowledge of the user.

At frequencies between 100 kHz and 450 MHz, the MPE may be exceeded if the radiated power is 1.4 W or less.

At frequencies between 450 and 1 500 MHz, the MPE may be exceeded if the radiated power is $1.4(450/f)$ W or less where f is the frequency in MHz.

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

4.3 Measurements

- 1) For both pulsed and non-pulsed fields at frequencies below 300 MHz, the power density, the square of the field strengths and the SARs, as applicable, are averaged over any 6-min or 30-min period. The time-averaged values should not exceed those given in Table 1, Part A and Table 2, Part A, or the exclusions in 4.2. Note that

the averaging time is a function of frequency above 15 GHz for a controlled environment and is a function of frequency between 1.34 and 3.0 MHz, and above 3 GHz for an uncontrolled environment. (The averaging time is also a function of frequency between 30 and 300 MHz for exposure to magnetic fields.)

In the case of induced currents, where RF shock or burn may be possible because of access to conductive structures, a 6-min or 30-min averaging time is no longer valid, and, for purposes of determining compliance with the recommended limits discussed in 4.1(a), the currents should be measured with an instrument having an averaging time no greater than 1 s. Induced body currents should be measured by determining the RF current flowing to ground through the feet of the individual. Contact currents should be measured by determining the RF current through the hand in contact with the ungrounded surface. The use of instrumentation which can simulate the impedance of the human body at the frequency of the current may be used to assess the maximum expected current that would flow if a person were to come into contact with an energized object. [B10] (See Fig A6.)

- 2) Generally, for frequencies less than 300 MHz, both the electric and magnetic field strengths shall be determined. For frequencies equal to or less than 30 MHz, this can *only* be accomplished by independent measurement of both the electric and magnetic field strengths; for frequencies between 30 and 300 MHz, it may be possible through analysis to show that measurement of only one of the two fields, not both, is sufficient for determining compliance with the MPE. For frequencies above 300 MHz, only one field component need be measured (generally E).
- 3) Measurements to determine adherence to the recommended MPE shall be made (with appropriate instruments) at distances 20 cm or greater from any object. See IEEE C95.3-1991 [1].
- 4) Evaluation of induced RF currents will generally require a measurement, unless the exposure situation is very simple. Most exposure conditions are complex and induced currents are not amenable to analysis. Induced currents may be measured by one or more of the following three methods:
 - a) RF thermocouple-type ammeter measurements—These devices, employing thermocouple elements for the measurement of RF currents, offer true rms detection and may be inserted directly in series with the conduction path for the current flow into the body, or exiting the body. While simple in design and use, thermocouple type ammeters have very limited tolerance for overload currents that can destroy the thermocouple element.
 - b) Voltage measurements—The induced current may also be determined by measuring the RF voltage developed across a noninductive resistor that is connected in series with the current path, as in (a). Either a broadband type of voltmeter, suitable for the frequency of the current, or a narrowband, tunable voltmeter in the form of a tuned receiver may be used to determine the voltage. The current is determined from the relation:

$$I=V/R$$

where

I =induced RF current (A)

V =RF voltage drop across the resistor (V)

R = impedance of the resistor (Ω)

Various forms of circuits making use of this basic method may be used for purposes of measuring the magnitude of the RF current flowing from the body to ground, including the use of parallel plate electrodes connected with a resistive element upon which an individual may stand. Commercial instruments with a flat frequency response between 3 kHz and 100 MHz are beginning to become available for this purpose, as are instruments with shoe-insertable sensors for personnel mobility.

- c) RF current transformer (current probe) measurements—RF current transformers are of the clamp-on type or the fixed window type. Either type may be used to measure the RF current flowing in a conductor. The current transformer consists of a toroidally wound transformer in which the current carrying conductor is typically placed in the window of the device and acts as the primary for the transformer. Current transformers may be used to determine the current flowing in a parallel plate electrode arrangement, as described in (b), or in conjunction with a conductive rod probe assembly to determine contact currents that might be experienced by a person touching an object exposed to RF fields. Generally, the current transformer requires some form of instrument to detect the output voltage from the transformer and subsequently, the current that flows through the window of the transformer.

In each of the three methods, it may be possible to insert an impedance equivalent to the human body at the frequency of interest that would permit a measurement of the induced current, without the current actually flowing in the body until after the evaluation of its magnitude.

In any of these methods, caution shall be exercised in the selection of the exact device for the measurement, since its frequency dependence will affect the measurement result. For example, thermocouple detectors used in some RF ammeters exhibit variations in their response to different frequencies (commonly becoming less efficient at higher frequencies), and current transformer performance characteristics are a compromise between sensitivity and bandwidth.

The meters, associated circuitry and methodology shall be appropriate for the particular frequency and the meters shall have an averaging time no greater than 1 second. When it is desired to make an indirect measurement of the current that might actually flow in a human, use of an antenna or phantom model may prove helpful. In this case, the phantom dipole moment, surface area, and contact impedance should be equivalent to those of the simulated subject.

4.4 Relaxation of Power Density Limits for Partial Body Exposures

The following relaxation of power density limits is allowed for exposure of all parts of the body *except* the eyes and the testes.

Compliance with the MPE of Tables 1 and 2 is determined from spatial averages of power density or the mean squared electric and magnetic field strengths over an area equivalent to the vertical cross-section of the human body (projected area) at a distance no closer than 20 cm from any object. For exposures in controlled environments, the peak value of the mean squared field strength should not exceed 20 times the square of the allowed spatially averaged values (Table 1) at frequencies below 300 MHz, and should not exceed the equivalent power density of 20 mW/cm² at frequencies between 300 MHz and 6 GHz, $20 (f/6)^{1/4}$ mW/cm² at frequencies between 6 and 96 GHz (f is in GHz), and 40 mW/cm² at frequencies above 96 GHz. Similarly, for exposures in uncontrolled environments, the peak value of the mean squared field strengths should not exceed 20 times the square of the allowed spatially averaged values (Table 2) at frequencies below 300 MHz, or the equivalent power density of 4 mW/cm² for f between 300 MHz and 6 GHz, $(f/1.5)$ mW/cm² for frequencies between 6 GHz and 30 GHz (f is in GHz), and 20 mW/cm² at frequencies above 30 GHz. At frequencies below 300 MHz, the equivalent maximum rms field strengths should not exceed 4.47⁴ times the maximum allowed spatially averaged values of E and H shown in Tables 1 and 2 (see 6.10). The relaxation for partial-body exposure is summarized in Table 3.

Table 3—Relaxations for Partial Body Exposures

	Frequency in GHz	Peak Value of Mean Squared Field	Equivalent Power Density in mW/cm ²
Controlled Environment	$0.0001 \leq f < 0.3$	$< 20 \bar{E}_s^2$ or $\bar{H}^2$ *	
	$0.3 < f \leq 6$		< 20
	$6 < f \leq 96$		$< 20(f/6)^{1/4} \ddagger$
	$96 < f \leq 300$		40
Uncontrolled Environment	$0.0001 \leq f < 0.3$	$< 20 \bar{E}_s^2$ or $20 \bar{H}^2 \dagger$	
	$0.3 < f \leq 6$		4
	$6 < f \leq 30$		$f/1.5 \ddagger$
	$30 < f \leq 300$		20

** DCL125 and DCL125 are the spatially averaged values from Table 1.
† DCL124 and DCL125 are the spatially averaged values from Table 2.
‡ f in GHz

5. Explanation

Exposure to electromagnetic fields in the resonance frequency range under consideration is but one of several sources of energy input to the human body. The MPE in a controlled environment results in energy deposition, averaged over the entire body mass for any 6-min period of about 144 J/kg or less. This is equivalent to an SAR of about 0.40 W/kg or less, as spatially and temporally averaged over the entire body mass.

Biological effects data that are applicable to humans for all possible combinations of frequency and modulation do not exist. Therefore, this standard has been based on the best available interpretations of the extant literature and is intended to prevent adverse effects on the functioning of the human body.

At low frequencies, the magnetic field limits have been relaxed relative to ANSI C95.1-1982 [B1]. An anatomically realistic model B26 of a human being has been used to show that the new limits will ensure SARs less than one twentieth of those specified (i.e., 0.4 and 0.08 W/kg). This is still very conservative, but more realistic than the H-field limits in ANSI C95.1-1982 .

The electric field limits at low frequencies in Table 1 are primarily dictated by the following two objectives:

- 1) limiting induced currents in the ankles during free-field exposure, and
- 2) lowering the probability of inducing large body currents when conducting objects are touched.

The limits on induced RF currents are based on two different considerations. First, *in any environment*, currents are limited to a level that prevents RF burns due to excessively high current densities in small areas of tissue while the subject is free standing in high-strength fields and has contact with conductive objects in which induced currents are flowing. This level, taken from [B10, B49, B54] is 100 mA, if measured through one foot, and 200 mA if measured through both feet. A value of 100 mA is applicable to contact situations, similar to a grasping contact with the hand. These currents will not result in localized SARs in the extremities (e.g., ankles or wrists) that exceed 20 W/kg, but may be perceived if protective clothing, such as insulated gloves, is not worn.

In controlled environments, various mitigative measures can be taken to reduce the probability of hazardous conditions. Such measures may include the following:

- 1) protective gloves or clothing,
- 2) awareness programs so that individuals are alerted to the possible presence of induced currents in conductive objects, and
- 3) specific work practices that lessen the probability of exposure.

Second, for frequencies between 0.003 and 0.1 MHz, the induced current *in controlled environments* is limited to reduce the probability of reactions caused by induced currents that exceed the perception threshold for grasping contact with energized objects [B10]. The perception threshold is frequency dependent below 0.1 MHz and the limiting current is given by

$$I = 1000f \text{ mA for } (0.003 < f \leq 0.1 \text{ MHz})$$

In uncontrolled environments, individuals will, in general, not be aware of the presence of induced currents in various objects illuminated with RF fields. Inadvertent contact by an individual with such objects could lead to burns or startle reactions that, while not hazardous per se, could lead to an accident. To reduce the probability of such startle reactions⁴, the contact current limit is based on laboratory data on perception of currents at different frequencies in humans [B10, B14]. These data indicate that perception thresholds, at any given frequency, depend on the type of contact made with the conducting object; touching contact generally results in lower current perception thresholds than grasping contact by a factor as great as ten. Accordingly, the current limits in Table 2 are based on grasping

⁴This does not include the startle reaction associated with spark discharges.

contact and limit the current to 4.5 mA at 10 kHz. In the frequency range of 0.1–100 MHz, the current perception thresholds are related to the sensation of heating and become relatively constant with increasing frequency. In this frequency range, the contact current is limited to 45 mA.

In some environments, the transient discharge phenomenon associated with initiating or breaking contact with energized conductors can lead to easily perceived shock effects even though the steady-state current flow, after complete contact is established, is within the limits prescribed in this standard. These effects are more directly related to the energy contained in the transient discharge and, consequently, measures of the open-circuit voltage and short-circuit current on the energized object may be better indicators of the potential for momentary shock effects. Data on such phenomena have not been sufficiently developed in the technical literature to permit quantitative limits on energy transfer that are related to perception thresholds. *Users of this standard are cautioned that such phenomena can exist and, when performing hazard assessments, they should investigate the possibility of transient discharges that may be perceptible and even cause startle reactions, but that result in steady-state currents that are within the guidelines.*

Above 6.0 GHz, the exposure in human tissue is quasi-optical and the SAR exclusion rule does not apply.

At higher frequencies, above 15 GHz, it is known that penetration depth is much less than 1 cm and thermal time constants drop to seconds as the infrared range is approached. Consequently, the MPE specifies continuous functions for the field limits and averaging time as frequency increases to the upper limit of 300 GHz.

Below 0.1 MHz the SAR exclusion rule does not apply. Instead, limits on internal current density can substitute as the basis for exclusion. These limits are based on the literature on electro-stimulation at low frequencies B8.

Exclusion criteria (4.2) to the MPE can be used in relation to fields from low-power devices such as hand-held, mobile, and marine radio transceivers. These devices may emit localized fields exceeding the MPE, but will result in a significantly lower rate of energy absorption than the whole-body averaged SARs that are allowed.

Exposures in excess of the MPEs are not necessarily harmful. However, in the absence of intended benefits (e.g., medical or lifesaving procedures), exposures above the MPE are not recommended.

6. Rationale

American National Standards Institute (ANSI) policy requires that each of its standards or guides be reviewed at five-year intervals. At the time of expiration, the standard or guide may be reaffirmed, revised, or rescinded in accordance with the consensus of the reviewing body. In 1982, extensive revisions of the earlier standard were introduced into ANSI C95.1-1982 based on improved dosimetry that defined frequency-dependent limits on fields and power density. The use of SAR as the basic dosimetric parameter permitted the formation of exclusion rules. Since 1982, Subcommittee IV has met at least once and usually twice annually to review a wide range of proposed refinements of the ANSI 1982 standard. The decision to expand the range of frequencies made it clear that quasi-static and quasi-optical considerations shall apply at the lower and higher boundary regions of the frequency range. Therefore, the applicability of SAR considerations was limited to the range from 0.1 MHz to 6.0 GHz, which includes the resonance range for human beings. Below 0.1 MHz, the data base on electro-stimulation of biological tissue plays the dominant role and the primary dosimetric parameter is internal current density. Above 6.0 GHz, the exposures are quasi-optical, and under these conditions, power density is the meaningful parameter.

In the broader resonance range, 0.1 MHz to 6.0 GHz, a primary question was the validity of the previously-adopted SAR criterion of 4 W/kg as a basis for standard setting. A total of 321 papers selected from the archival literature (Appendix A) was reviewed for biological, engineering, and statistical validity (see 6.3). It was agreed that only peer-reviewed reports of studies at $\text{SAR} \leq 10 \text{ W/kg}$, which had received favorable engineering and biological validation, should be considered relevant to the assessment of risk from exposure to electromagnetic fields in the resonance range. The literature review was followed by extensive deliberations of the Risk Assessment Working Group that was charged to reach agreement on an SAR at which potentially-deleterious health effects are likely to occur in human beings. A

majority of the Risk Assessment Working Group agreed that the literature is still supportive of the 4 W/kg criterion. Further, the ANSI 1982 safety factor of 10 was reaffirmed by Subcommittee IV, yielding an SAR of 0.4 W/kg as the working basis for the MPE. The question then arose of the need for two tiers of MPE (as adopted by NCRP, 1986 B52) to distinguish occupational vs. general public exposures.

To some, it would appear attractive and logical to apply a larger, or different, safety factor to arrive at the guide for the general public. Supportive arguments claim subgroups of greater sensitivity (infants, the aged, the ill and disabled), potentially greater exposure durations (24-hr/day vs. 8-hr/day), adverse environmental conditions (excessive heat and/or humidity), voluntary vs. involuntary exposure, and psychological/emotional factors that can range from anxiety to ignorance. Non-thermal effects, such as efflux of calcium ions from brain tissues, are also mentioned as potential health hazards. The members of Subcommittee IV believe the recommended exposure levels should be safe for all, and submit as support for this conclusion the observation that no reliable scientific data exist indicating that:

- 1) Certain subgroups of the population are more at risk than others,
- 2) Exposure duration at ANSI C95.1-1982 levels is a significant risk,
- 3) Damage from exposure to electromagnetic fields is cumulative, or
- 4) Nonthermal (other than shock) or modulation-specific sequelae of exposure may be meaningfully related to human health.

No verified reports exist of injury to human beings or of adverse effects on the health of human beings who have been exposed to electromagnetic fields within the limits of frequency and SAR specified by previous ANSI standards, including ANSI C95.1-1982 . In the promulgation of revised guidelines, the responsibility of the current Subcommittee IV is adherence to the scientific base of data in the determination of exposure levels that will be safe not only for personnel in the working environment, but also for the public at large. The important distinction is not the population type, but the nature of the exposure environment. When exposure is in a controlled environment, the scientifically-derived exposure limits apply. When exposure is in an uncontrolled environment, however, an extra safety factor is applied under certain conditions; these include, but are not limited to, the following:

- 1) Exposure in the resonant frequency range, and
- 2) Low-frequency exposure to electric fields where exposure is penetrating or complicated by associated hazards like RF shocks or burns induced by metal contacts.

As defined earlier, uncontrolled environments include the domicile and most places where the infirm, the aged, and children are likely to be. It also includes the work environment where employees are not specifically involved in the operation or use of equipment that does or may radiate significant electromagnetic energy and where there are no expectations that the exposure levels may exceed those shown in Table 2. On the other hand, controlled environments may involve exposure of the general public as well as occupational personnel, e.g., in passing through areas such as an observation platform near a transmitting tower where analyses show the exposure may be above that shown in Table 2 but is below that in Table 1. Other exposure conditions include that of the radio amateur who voluntarily and knowledgeably operates in a controlled RF environment.

At frequencies below 3 MHz, the MPEs, in terms of magnetic fields, have been relaxed to more reasonably correspond to whole-body SAR limits. On the other hand, the MPEs, in terms of E field, continue to be capped below 3 MHz in order to limit the possibility of reactions (shocks or burns) at the surface of the body that might occur in E fields of high strength, especially under conditions of spatial and temporal field concentration.

In this standard, there are extensive modifications of the averaging time for determining permissible exposure. At the upper frequencies, these rules agree with soundly-based averaging times derived from optical considerations. At the lower frequencies, new rules on induced currents have been introduced to prevent RF shock or burn upon grasping contact with an object in an RF environment. These rules supplement the limits on E and H field exposure.

This standard is thus an extension of ANSI C95.1-1982 , and incorporates many refinements that will serve to make the MPEs more useful in a greater variety of exposure situations. There remain areas, however, which the standard does not cover, e.g., the possible exposure of the body to transient spark-discharge phenomena upon touching a large

conducting object in an RF environment. Future research may provide, the data base from which quantitative rules for preventing adverse effects from such discharges can be derived.

Research on the effects of chronic exposure and speculations on the biological significance of nonthermal interactions have not yet resulted in any meaningful basis for alteration of the standard. It remains to be seen what future research may produce for consideration at the time of the next revision of this standard.

6.1 Recognition of Whole-Body Resonance

As is true of ANSI C95.1-1982 [B10], the MPE in this standard is based on recommendations of field strengths or of plane-wave-equivalent power densities of incident fields, but these limits are based on well established findings that the body, as a whole, exhibits frequency-dependent rates of absorbing electromagnetic energy [B6, B20, B21, B25]. Whole-body-averaged SARs approach maximal values when the long axis of a body is parallel to the E-field vector and is four tenths of a wavelength of the incident field. Maximal absorption occurs at a frequency near 70 MHz for Standard Man (height = 175 cm) and results in an approximate seven-fold increase of absorption relative to that in a 2450 MHz field [B22, B27]. In consideration of this dependency, recommended MPEs of field strength have been reduced across the range of frequencies in which human bodies from infants to large adults exhibit whole-body resonance. Above 6 GHz, the absorption is quasi-optical and body resonance considerations do not apply.

6.2 Incorporation of Dosimetry

Dosimetry is the fundamental process of measuring physical quantities of energy or substances that are imparted to an absorbing body [B40, B41]. In 1972, The National Council on Radiation Protection and Measurements (NCRP) convened Scientific Committee 39 to deliberate and recommend dosimetric quantities and units applicable to electromagnetic fields [B51]. In keeping with the NCRP recommendations, in 1982 the ANSI C95 Subcommittee IV adopted the unit-mass, time-averaged rate of electromagnetic energy absorption, as specified in units of watts per kilogram (W/kg). The quantity expressed by these units is termed the specific absorption rate (SAR).

Formally defined, the SAR is the time rate at which radio-frequency electromagnetic energy is imparted to an element of mass of a biological body. The SAR is applicable to any tissue or organ of interest (that is, can be applied to any macroscopic element of mass) or, as utilized in ANSI C95.1-1982 [B1], is expressed as a whole-body average. Ideally, anatomical distributions of SARs would be used explicitly to formulate a guide in recognition that absorption of electromagnetic energy from even the most uniform field can result in highly variable anatomical depositions of energy. It has been established [B31, B34, B35] through thermographic analyses of models of rats and man, and cadavers of rabbits, that spatial peak SAR values can exceed a whole-body average value by more than a factor of 20. Comparable findings have been reported [B27]. However, several factors preclude explicit use of peak SAR, such as the following:

- 1) The availability of data on distributive SARs is limited, and
- 2) SAR distributions are highly variable, since they depend on wavelength, polarization, and zone of the incident field, as well as on the mass and momentary geometry of the biological body.

The number of the possible SAR distributions approaches infinity. It is recognized, however, that a whole-body averaged SAR is the mean of a distribution, the high side of which is an envelope of electrical hotspots. These range from the mean value to the peak value, and when integrated with localized SARs of less than the mean value, are equal to the whole-body average. Moreover, for any given orientation of a given species in a given field, the correlation between the magnitude of a whole-body-averaged SAR and that of any lower or higher part-body SAR approaches unity. That is, if the power density of an incident electromagnetic field is increased, then the relative increase of the whole-body SAR will be directly proportional to the increase of any part-body SAR. Because of the invariable presence of electrical hotspots in the irradiated body and the inherent correlation between magnitudes of whole-body and part-body SARs, a biological effect induced by a localized SAR that is well above the whole-body average will be reflected to some extent by that average. The predictive utility of the correlation between part and whole has long