

C95.6™

IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0–3 kHz

IEEE Standards Coordinating Committee 28

IEEE International Committee on
Electromagnetic Safety on Non-Ionizing Radiation



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Sponsor

**IEEE International Committee on Electromagnetic Safety
(Standards Coordinating Committee 28) on Non-Ionizing Radiation**

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Abstract: Recommendations are given to prevent harmful effects in human beings exposed to electromagnetic fields in the frequency range of 0–3 kHz. The recommendations are intended to apply to exposures of the general public, as well as to individuals in controlled environments. They are not intended to apply to the purposeful exposure of patients by or under the direction of practitioners of the healing arts and may not be protective with respect to the use of medical devices or implants. A rationale that describes how the recommendations were arrived at, and the factors taken into account in formulating them, is included.

Keywords: contact currents, electric fields, electrical excitation, electromagnetic fields, electrostimulation, exposure limits, magnetic fields, non-ionizing radiation protection, safety levels

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Introduction

(This introduction is not part of IEEE Std C95.6-2002, IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0–3 kHz.)

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 accredited standards committee C95 and submitted to the American National Standards Institute (ANSI) for approval and issuance as ANSI C95 standards. Between 1988 and 1990, the committee was converted to Standards Coordinating Committee 28 under sponsorship of the IEEE Standards Board, and in 2001, became also known as the International Committee on Electromagnetic Safety (ICES). 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 ICES is:

“Development of standards for the safe use of electromagnetic energy in the range of 0 Hz–300 GHz relative to the potential hazards due to exposure of such energy to man, volatile materials, and explosive devices. The committee will coordinate with other committees whose scopes are contiguous with ICES.”

ICES is responsible for this standard. There are five subcommittees concerned with:

- I Techniques, Procedures, Instrumentation, and Computation,
- II Terminology, Units of Measurements, and Hazard Communication,
- 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.

Two standards, two guides, and three recommended practices have been issued. Current versions are:

IEEE Std C95.1™-1999 Edition, IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz–300 GHz (Replaces IEEE Std C95.1-1991).

IEEE Std C95.2™-1999, IEEE Standard for Radio Frequency Energy and Current Flow Symbols (Replaces ANSI C95.2).

IEEE Std C95.3™-1991 (Reaff 1997), IEEE Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields—RF and Microwave (Replaces ANSI C95.3-1973 and ANSI C95.1-1981).

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

IEEE Std 1460™-1996, IEEE Guide for the Measurement of Quasi-Static Magnetic and Electric Fields.

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

This standard was developed by an ICES Subcommittee 3 (SC 3) formed in 1991 to address the frequency range from 0–3 kHz (SC 3). In the early years, the subcommittee discussed the science relating to both long-

term and short-term exposures and concluded that the effects of long-term (chronic) exposure were not convincingly established as were effects of short-term exposures.

Disclaimer

This IEEE standard was developed through the collaborative effort of an international group of volunteers with expertise in many disciplines ranging from medicine to engineering. While this standard represents a consensus among this volunteer group, it is not the only view on the safety issues addressed herein. As with any guidance, use of this standard, does not provide proof of or guarantee of absolute safety. Use and compliance with this IEEE standard is wholly voluntary.

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Grateful appreciation is expressed to J. Patrick Reilly for his major contributions to this standard through technical development, his chairmanship of the Working Group responsible for its development, his drafting of this standard, and his gracious permission to adapt the material in this standard from his own numerous publications on this subject.

The Committee also recognizes the contributions to this standard by the previous Subcommittee co-chairs, John A. Bergeron and William E. Feero.

In memoriam, we wish to recognize Matthew Mingoia, who served as Secretary of Subcommittee 3 from its formation in 1991 until his death in 2000, for his total dedication and support of the activities of the Subcommittee and his contributions to the development of this standard.

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IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0–3 kHz

1. Overview

This standard is divided into six clauses. Clause 1 defines the scope and purpose of the standard. Clause 2 lists references to other standards that are useful in applying this standard. Clause 3 provides definitions that are either not found in other standards or have been modified for use with this standard. Clause 4 defines the protected population and the mechanisms of interaction. Clause 5 defines the exposure limits. Clause 6 details the rationale used in developing this standard.

1.1 Scope

This standard defines exposure levels to protect against adverse effects in humans from exposure to electric and magnetic fields at frequencies from 0–3 kHz. This standard was developed with respect to *established* mechanisms of biological effects in humans from electric and magnetic field exposures. It does not apply to exposures encountered during medical procedures. The defined exposure limits do not necessarily protect against interference of medical devices or problems involving metallic implants (see 6.12).

Established human mechanisms fall within the category of short-term effects. Such effects are understood in terms of recognized interaction mechanisms. Exposure limits defined in this standard are not based on the potential effects of long-term exposure because:

- a) There is not sufficient, reliable evidence to conclude that long-term exposures to electric and magnetic fields at levels found in communities or occupational environments are adverse to human health or cause a disease, including cancer.
- b) There is no confirmed mechanism that would provide a firm basis to predict adverse effects from low-level, long-term exposure.

The Subcommittee is aware of reported epidemiological associations between long-term exposure to magnetic fields and disease, including childhood leukemia in residential environments and chronic lymphocytic leukemia in occupational environments. The interpretation of these associations is unclear, especially since exposure to magnetic fields does not appear to initiate or advance the development of leukemia or other forms of cancers and other diseases in animals exposed over much of their lifetime. This is

consistent with the findings of interdisciplinary panels of scientists that have evaluated the literature on long-term exposures for scientific and governmental organizations. The most recent of these major reviews include the Advisory Group on Non-Ionizing Radiation of the UK National Radiological Protection Board (AGNIR [B3]¹), the Health Council of the Netherlands (Netherlands [B63]), the U.S. National Institute of Environmental Health Sciences (NIEHS [B64]; Olden [B68]), the Institution of Electrical Engineers (IEE [B45]), the International Agency for Research on Cancer (IARC [B42]), the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [B43], and the U. S. National Research Council (NRC [B65]).

Because none of the above reviews concluded that any hazard from long-term exposure has been confirmed, this standard does not propose limits on exposures that are lower than those necessary to protect against adverse short-term effects. The Subcommittee will continue to evaluate new research and will revise this standard should the resolution of present uncertainties in the research literature identify a need to limit long-term exposures to values lower than the limits of this standard. The Subcommittee will also continue to evaluate new research on short-term effects and modeling. As stated below, this standard makes reasonable assumptions based upon available data. As new data becomes available, the committee will revisit these assumptions for future revisions.

1.2 Purpose

The IEEE has previously defined safety standards for human exposure to electromagnetic fields in the frequency regime from 3 kHz–300 GHz (IEEE [B46]). The purpose of this standard is to define exposure standards for the frequency regime 0–3 kHz. For pulsed or nonsinusoidal fields, it may be necessary to evaluate an acceptance criterion at frequencies outside this frequency regime as explained in 5.2.4.2.

2. References

This standard shall be used in conjunction with the following publications:²

Accredited Standards Committee C2-1997, National Electrical Safety Code[®] (NESC[®]).³

IEEE Std 644[™]-1994, IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines.⁴

IEEE Std 1460[™]-1996, IEEE Guide for the Measurement of Quasi-Static Magnetic and Electric Fields.

3. Definitions, acronyms, and symbols

3.1 Definitions

For the purposes of this standard, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition [B47], shall be referenced for terms not defined in this clause.

3.1.1 action potential: A response of a nerve cell to a stimulus involving a propagating rapid depolarization of the potential across the cell membrane.

¹The numbers in brackets correspond to those of the bibliography in Annex A.

²The IEEE standards referred to in Clause 2 are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

³The NESC is available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

⁴IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

3.1.2 adverse effect: An effect detrimental to the health of an individual due to exposure to an electric or magnetic field, or a contact current.

3.1.3 adverse reaction factor (F_a): A multiplier used to derive maximum permissible exposure (MPE) levels, which converts from a threshold reaction to an adverse one.

3.1.4 averaging distance: The distance over which the *in situ* electric field is averaged when determining compliance with basic restrictions.

3.1.5 averaging time: The appropriate time period over which exposure is averaged for purposes of determining compliance with a maximum permissible exposure (MPE) or Reference Level.

3.1.6 axial cross section: A cross section of the body taken in a plane perpendicular to its long axis.

3.1.7 axial exposure: Exposure by a magnetic field perpendicular to the axial cross section.

3.1.8 basic restrictions: Limitations on the *in situ* electrical forces that avoid adverse effects, and with an acceptable safety factor.

3.1.9 biphasic: A waveform that has a reversal of polarity.

3.1.10 cardiac excitation: The electrical stimulation of a cardiac contraction.

3.1.11 central nervous system (CNS): The portion of the vertebrate nervous system consisting of the brain and spinal cord, but not including the peripheral nerves.

3.1.12 cerebral cortex: The convoluted thin layer of brain cells (gray matter) forming the outer surface of each cerebral hemisphere.

3.1.13 conductivity: A property of materials that determines the magnitude of the electric current density when an electric field is impressed on the material, expressed in units of siemens per meter (S/m); the inverse of resistivity.

3.1.14 contact current: Current passed into a biological medium via a contacting electrode or other source of current.

3.1.15 controlled environment: An area that is accessible to those who are aware of the potential for exposure as a concomitant of employment, to individuals cognizant of exposure and potential adverse effects, or where exposure is the incidental result of passage through areas posted with warnings, or where the environment is not accessible to the general public and those individuals having access are aware of the potential for adverse effects.

3.1.16 corona (air): A luminous discharge due to ionization of the air surrounding a conductor caused by a voltage gradient exceeding a certain critical value.

3.1.17 coronal cross section: A cross section taken through the long axis of the body in a plane parallel to its front view.

3.1.18 coronal exposure: Exposure by a magnetic field perpendicular to the coronal cross section.

3.1.19 depolarization (cellular): The reduction of the resting potential across a cellular membrane.

3.1.20 direct electrostimulation: Stimulation via the electric field within the biological medium induced by an external electric or magnetic field without direct contact with other conductors or spark discharges.

3.1.21 electric field strength (E): Force exerted by an electric field on an electric point charge, divided by the electric charge. Electric field strength is expressed in newtons per coulomb or volts per meter ($N/C = V/m$).

3.1.22 electrostimulation: Induction of a propagating action potential in excitable tissue by an applied electrical stimulus; electrical polarization of presynaptic processes leading to a change in post synaptic cell activity.

3.1.23 environmental field: An electric or magnetic field external to the body and measured in the absence of the body.

3.1.24 established mechanism: A bioelectric mechanism having the following characteristics: (a) can be used to predict a biological effect in humans; (b) an explicit model can be made using equations or parametric relationships; (c) has been verified in humans, or animal data can be confidently extrapolated to humans; (d) is supported by strong evidence; and (e) is widely accepted among experts in the scientific community.

3.1.25 extra systole: An induced cardiac contraction, usually a premature contraction that interrupts the normal sinus rhythm; a forced heartbeat.

3.1.26 general public: All individuals who may experience exposure, except those in controlled environments.

3.1.27 grasping contact: An electrical connection with a large energized conductor made by firmly holding the conductor in the hand. In this standard, a contact area of 15 cm^2 is assumed for such contact.

3.1.28 Hall-effect voltage: The voltage developed between two points within a conductive medium due to the redistribution of moving charges in a magnetic field.

3.1.29 indirect electrostimulation: Stimulation through contact with a conducting object under the influence of an electric or magnetic field, including spark discharges.

3.1.30 induction: An electric or magnetic field in a conducting medium caused by the action of a time-varying external (environmental) electric or magnetic field.

3.1.31 *in situ*: Within biological tissue.

3.1.32 let-go current: The threshold current level at which involuntary muscular contraction prevents release of a grip on an energized conductor.

3.1.33 lognormal distribution: A statistical distribution in which the logarithm of the statistical variate is normally distributed.

3.1.34 Lorentz force: The force on a moving charge within a magnetic field.

3.1.35 magnetic field strength (H): The magnitude of the magnetic field vector; expressed in units of amperes per meter (A/m).

3.1.36 magnetic flux density (B): A vector quantity that determines the force on a moving charge or charges (electric current). Magnetic flux density is expressed in teslas (T). One gauss (deprecated unit) equals 10^{-4} T .

3.1.37 magnetohydrodynamic effect: A force or potential imparted on a fluid volume arising from its motion in the presence of a magnetic field.

3.1.38 maximum permissible exposure (MPE): The rms and peak electric and magnetic fields and contact currents to which a person may be exposed without an adverse effect and with acceptable safety factors. The MPE for magnetic field exposure in this standard may be exceeded if it can be demonstrated that the basic restrictions are not exceeded.

3.1.39 mean: The arithmetic average of a series of measurements or other data.

3.1.40 median: The value within a statistical distribution at which 50% of data are above and below.

3.1.41 median threshold: The threshold value within a statistical distribution at which 50% of subjects have greater thresholds and 50% have lesser thresholds.

3.1.42 monophasic: A waveform not reversing in polarity.

3.1.43 motor neuron: (a) A central neuron that initiates excitation of a peripheral nerve; (b) a peripheral nerve that innervates muscle. Definition (b) is generally used in this standard.

3.1.44 myelinated nerve: A nerve fiber containing insulating myelin sheaths that are interrupted by uninsulated segments called *nodes of Ranvier*.

3.1.45 nerve: A bundle of axons.

3.1.46 nerve fiber: A single nerve axon.

3.1.47 neuron: A single cellular unit usually consisting of an axon, cell body, and dendritic tree.

3.1.48 nonuniform field: A field that is not constant in amplitude, direction, and relative phase over the dimensions of the body or body part under consideration. In the case of electric fields, the definition applies to an environmental field undisturbed by the presence of the body.

3.1.49 normal load conditions: The maximum operating voltage and current of an electric power transmission line under conditions that exclude outages, or other emergency operating conditions.

3.1.50 open-circuit voltage: The potential difference between two conducting objects without a current load being applied to the objects.

3.1.51 peripheral nerve: Nerve found outside the central nervous system and leading to and from the central nervous system.

3.1.52 phase duration (t_p): The time between zero crossings of a waveform having zero mean. For a sine-wave of frequency f , $t_p = 1/(2f)$. For an exponential waveform, t_p is interpreted as the duration measured from the waveform peak to a point at which it decays to $0.37 (e^{-1})$ of its peak value.

3.1.53 phosphene: Visual sensation caused by nonphotic stimuli. Electro-phosphenes are induced by electric currents; magneto-phosphenes are induced magnetically.

3.1.54 polarization (cellular): The electric potential formed across a cell membrane.

3.1.55 postsynaptic cell: The cell receiving excitation in a synaptic junction between two nerve cells.

3.1.56 presynaptic cell: The cell that provides excitation at a synapse, usually by release of a neurotransmitter.

3.1.57 probability factor (F_p): A multiplier used in the derivation of maximum permissible exposure (MPE) or reference levels, which converts a median threshold to a low probability one ($\leq 1\%$).

3.1.58 proposed mechanism: A bioelectric mechanism lacking the characteristics of an established mechanism. (See also: *established mechanism*.)

3.1.59 relative phase: The phase angle of a sinusoidal waveform relative to the phase angle of another waveform measured at a different point within the conductive medium or with respect to a stated reference waveform.

3.1.60 rheobase: The minimum threshold intensity in a strength-duration relationship (applicable to a stimulus duration that is long in comparison with the strength-duration time constant). Also applied to the minimum plateau in a strength-frequency relationship.

3.1.61 root-mean-square (rms): A mathematical operation on a series of measurements (or a temporal sequence of data) in which the square root of the arithmetic mean of the squares of the measurements or data is taken.

3.1.62 safety factor (F_s): A multiplier (≤ 1) used to derive maximum permissible exposure (MPE) levels, which provides for the protection of exceptionally sensitive individuals, uncertainties concerning threshold effects due to pathological conditions or drug treatment, uncertainties in reaction thresholds, and uncertainties in induction models.

3.1.63 sagittal cross section: A cross section along the long axis of the body, parallel to its side view.

3.1.64 sagittal exposure: Exposure by a magnetic field perpendicular to the sagittal cross section.

3.1.65 short-term response: A biological response to an electric or magnetic stimulus manifested within a few seconds after the exposure begins.

3.1.66 spark discharge: The transfer of current through an air gap requiring a voltage high enough to ionize the air, as opposed to direct contact with a source.

3.1.67 specific absorption rate (SAR): The time derivative of the incremental energy absorbed by (dissipated in) an incremental mass contained in a volume element of given density. SAR is expressed in watts per kilogram (W/kg).

3.1.68 strength-duration curve: The functional relationship between the threshold of excitation and the duration of an excitatory stimulus.

3.1.69 strength-duration time constant (τ_e): The functional parameter in a strength-duration curve that describes the temporal inflection point between the rheobase and the rising threshold segment.

3.1.70 strength-frequency curve: The functional relationship between the threshold of excitation and the frequency of an excitatory stimulus.

3.1.71 synapse: The site of functional apposition between two neurons at which an electrical signal from one neuron is transmitted to another by either electrical or chemical means. In the typical synapse, the impulse is transmitted by a chemical substance called a *neurotransmitter*.

3.1.72 systole: Contraction of the heart.

3.1.73 threshold: The level of a stimulus marking the boundary between a response and a nonresponse.

3.1.74 touch contact: A contact of small area made between the human body and an energized conductor. In this standard, a contact area of one cm² is the assumed touch contact area.

3.1.75 uniform field: A field that is constant in amplitude, direction, and relative phase over the dimensions of the body or body part under consideration. In the case of electric fields, the definition applies to an environmental field undisturbed by the presence of the body.

3.1.76 ventricular fibrillation: Arrhythmia of the ventricles of the heart characterized by rapid uncoordinated contractions.

3.1.77 visual evoked potential (VEP): An endogenous potential ensuing in the brain and measured on the scalp in response to a visual stimulus.

3.1.78 voxel: A three-dimensional computational element.

3.1.79 waveform: The variation of an electrical amplitude with time. Unless otherwise stated, in this standard the term *waveform* refers to values (or measurements) at sites within the biological medium.

3.2 Acronyms and abbreviations

B-field Magnetic flux density

CNS Central nervous system

E-field Electric field strength

ECT Electroconvulsive therapy

EMC Electromagnetic compatibility

IARC International Agency for Research on Cancer

ICNIRP International Commission on Non-Ionizing Radiation Protection

IEE Institute of Electrical Engineers (United Kingdom)

MPE Maximum permissible exposure

MRI Magnetic resonance imaging

NIEHS National Institute of Environmental Health Sciences (USA)

NRC National Research Council (USA)

rms Root-mean-square

SAR Specific absorption rate

S-D Strength-duration (time constant, curve, etc.)

VEP Visual evoked potential

VF Ventricular fibrillation

3.3 Symbols

a, b	Semi-major and semi-minor axes of elliptical representation of exposed body part.
A_i	The magnitude of the i th Fourier component of a waveform.
B	Magnetic flux density, expressed in tesla (T). Tesla and gauss (G) units are related by $1 \text{ G} = 10^{-4} \text{ T}$.
B_o	The minimum flux density in a strength-duration or strength-frequency relationship (T).
$\dot{B}$	Time rate of change of magnetic flux density, dB/dt , expressed as teslas-per-second (T/s).
$\dot{B}_p$	Peak allowable limit on the time derivative of flux density.
d_a	Averaging distance used to determine compliance with an <i>in situ</i> electric field basic restriction.
d_e	Spatial extent of an <i>in situ</i> electric field.
E	Electric field strength, expressed in volts-per-meter (V/m).
E_o	The minimum (rheobase) electric field strength in a strength-duration or strength-frequency relationship (V/m).
E_{ot}	Rheobase threshold electric field strength.
E_{ob}	Rheobase basic restriction.
E_i	<i>In situ</i> electric field (V/m).
f	Frequency, expressed in hertz (Hz).
f_e	Upper transition frequency in a strength-frequency relation (Hz).
f_i	Frequency of the i th Fourier component of a waveform.
F_a	Adverse reaction factor.
F_p	Probability factor.
F_s	Safety factor.
h	Height of standing person, expressed in meters (m).
H	Magnetic field intensity, expressed in amperes-per-meter (A/m). Related to flux density by $B = \mu H$.
I_c	Contact current, expressed in amperes (A).
J	Current density, expressed in amperes-per-square meter (A/m^2).
ME_i	Maximum allowable exposure of either the <i>in situ</i> electric field, the environmental field, or the contact current at frequency f_i .
μ	Magnetic permeability, expressed in henries-per-meter (H/m).