

IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz

IEEE Standards Coordinating Committee 39

Developed by the
IEEE International Committee on Electromagnetic Safety



IEEE
3 Park Avenue
New York, NY 10016-5997
USA

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IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz

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IEEE International Committee on Electromagnetic Safety

Approved 8 February 2019

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Abstract: Safety limits for the protection of persons against the established adverse health effects of exposures to electric, magnetic, and electromagnetic fields in the frequency range 0 Hz to 300 GHz are presented in this standard. These exposure limits are intended to apply generally to persons permitted in restricted environments and to the general public in unrestricted environments. These exposure limits are not intended to apply to the exposure of patients by or under the direction of physicians and medical professionals, as well as to the exposure of informed volunteers in medical or scientific research studies, and might not be protective with respect to the use of medical devices or implants.

Keywords: dosimetric reference limit (DRL), exposure reference level (ERL), induced and contact currents, electric fields, electrical excitation, electromagnetic fields, electrostimulation, general public, IEEE C95.1™, magnetic fields, non-ionizing radiation protection, radio frequency (RF), RF exposure, RF safety, restricted environment, specific absorption rate (SAR), unrestricted environment

The Institute of Electrical and Electronics Engineers, Inc.
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Participants

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Chung-Kwang Chou, *Chair (TC95)*
Ronald Petersen*, *Secretary (TC95)*
Kevin Graf, *Co-Chair (SC3)*
Robert Kavet, *Co-Chair (SC3)*
Artnarong Thansandote, *Co-Chair (SC4)*
Marvin Ziskin, *Co-Chair (SC4)*

Max Amann
Vitas Anderson
William Bailey
Quirino Balzano
Barbara Benassi
John Bergeron
Ralf Bodemann
Ian Brooker
Jerrold Bushberg
Matt Butcher
Robert Cleveland
Selçuk Çömlekçi
Claudia Consales
Benjamin Cotts
Robert Curtis
Valerio De Santis
Amnon Duvdevany
Joe Elder
Antonio Faraone
Kevin Fisher
Kenneth Foster
James Futch
Sami Gabriel
Paolo Galloni

Kenneth Gettman
Olin Giles
Martin Gledhill
Donald Haes
Tim Harrington†
James Hatfield
Tamera Hay
Akimasa Hirata
Masateru Ikehata
Michel Israel
Robert Johnson
Kenneth Joyner
Efthymios Karabetsos
Jafar Keshvari
Nam Kim
B. Jon Klauenberg
Masami Kojima
Ilkka Laakso
Ae-Kyoung Lee
Alexandre Legros
Jeffrey Lodwick
Rajat Mathur
David Maxson

Marty Meltz*
Caterina Merla
Hiroaki Miyagi
John Moulder
Flavia Novelli
Chiyoji Ohkubo
John Osepchuk
Claudio Pioli
J. Patrick Reilly
Wesley Shelton
Asher Sheppard
Myrtill Simko
William Slovinsky
Mays Swicord
Richard Tell
Paul Testagrossa
Christer Törnevik
Vijayalaxmi
Marvin Wessel
Jeffrey Whitmore
Kenichi Yamazaki
Roger (Chris) Young
Olga Zeni
Peter Zollman†

* Deceased

† Editing assistant

The following members of the individual balloting committee voted on this standard. Balloters may have voted for approval, disapproval, or abstention.

Reza Arefi
Curtis Ashton
William Bailey
Ralf Bodemann
Roger Boyell
Joe Boyles
Bill Brown
Demetrio Bucaneg Jr.
William Bush

Jerrold Bushberg
William Byrd
Pin Chang
Chung-Kwang Chou
Keith Chow
Robert Curtis
Ray Davis
John Defrank
Mark Douglas

Donald Dunn
Lars Foged
Jeffrey Fordham
Avraham Freedman
Sami Gabriel
James Gilb
Randall Groves
Donald Haes
James Hatfield

Werner Hoelzl
Kenneth Joyner
Laszlo Kadar
Efthymios Karabetos
Robert Kavet
Peter Kelly
Tanuj Khandelwal
Yuri Khersonsky
Jim Kulchisky
Niels Kuster

Michael Lauxman
Joseph Levy
Jon Martens
Edward McCall
Matthias Meier
Vikass Monebhurrin
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Gearold O. H. Eidhin
John Osepchuk
Iulian Profir
Lakshman Raut

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Ryandi Ryandi
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Nikunj Shah
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Thomas Koshy
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Kevin Lu
Daleep Mohla
Andrew Myles

Annette D. Reilly
Dorothy Stanley
Sha Wei
Phil Wennblom
Philip Winston
Howard Wolfman
Feng Wu
Jingyi Zhou

*Member Emeritus

Participants

A corrigenda for this standard was prepared by Subcommittee 3 (Safety Levels with Respect to Human Exposure 0 – 3 kHz) and Subcommittee 4 (Safety levels with Respect to Human Exposure, 3 kHz – 300 GHz) of IEEE ICES TC95. The following persons contributed to the development of this corrigenda or participated in TC95 balloting:

Chung-Kwang Chou, *Chair (TC95)*

Vitas Anderson
Bill Bailey
Quirino Balzano
Ralf Bodemann
Jerrold Bushberg
Matt Butcher
Robert Cleveland
Benjamin Cotts
Robert Curtis
Mark Douglas
Amnon Duvdevany
Joe Elder
Roel Escobar
Antonio Faraone
Kevin Fisher
Kenneth Foster
James Futch

Sami Gabriel
Kenneth Gettman
Kevin Graf
Donald Haes
Tim Harrington[†]
James Hatfield
Akimasa Hirata
Masateru Ikehata
Robert Johnson
Kenneth Joyner
Efthymios Karabetsos
Robert Kavet
Jafar Keshvari
Nam Kim
B. Jon Klauenberg
Niels Kuster

Ilkka Laakso
Ae-Kyoung Lee
Rajat Mathur
David Maxson
Hiroaki Miyagi
John Osepchuck
Patrick Reilly
Richard Tell
Paul Testagrossa
Artnarong Thansandote
Christer Törnevik
Robert Weller
Marv Wessel
Kenichi Yamazaki
Chris Young
Marvin Ziskin
Peter Zollman[†]

[†] Editing assistant

The following members of the individual balloting committee voted on this corrigenda. Balloters may have voted for approval, disapproval, or abstention.

Vitas Anderson
Reza Arefi
William Bailey
Demetrio Bucaneg Jr.
Jerrold Bushberg
Matt Butcher
William Byrd
Pin Chang
Chung-Kwang Chou
Robert Curtis
Valerio De Santis
Mark Douglas
Roel Escobar
Antonio Faraone
Kenneth Foster
Avraham Freedman
Sami Gabriel
James Gilb
Kevin Graf

Randall Groves
Donald Haes
Tim Harrington
James Hatfield
Akimasa Hirata
Werner Hoelzl
Masateru Ikehata
John John
Robert Johnson
Kenneth Joyner
Laszlo Kadar
Efthymios Karabetsos
Piotr Karocki
Robert Kavet
Yuri Khersonsky
Nam Kim
B. Jon Klauenberg
Joseph L. Koepfinger
Jim Kulchisky

Benjamin Lanz
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Rajat Mathur
David Maxson
John Osepchuk
John Roman
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Wesley Shelton
Gary Smullin
Walter Struppler
Richard Tell
Artnarong Thansandote
Matthew Wakeham
Robert Weller
Marvin Wessel
Kenneth White
Roger Young
Jian Yu
Marvin Ziskin

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Andrew Myles

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Dorothy Stanley
Sha Wei
Phil Wennblom
Philip Winston
Howard Wolfman
Feng Wu
Jingyi Zhou

*Member Emeritus

Introduction

This introduction is not part of IEEE Std C95.1-2019, IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz.

In 1960, the American Standards Association approved the initiation of the Radiation Hazards Standards project under the co-development of the Department of the Navy and the Institute of Electrical and Electronics Engineers, Incorporated (IEEE; called the “Institute of Radio Engineers (IRE)” at the time). 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 the “Standards Coordinating Committee 28 (SCC28)” under the development of the IEEE Standards Board. In 2001, the IEEE Standards Association Standards Board approved the name “International Committee on Electromagnetic Safety (ICES)” for SCC28 to better reflect the scope of the committee and its international membership. In accordance with the policies of the IEEE, C95 standards are issued and developed as IEEE standards and submitted to ANSI for recognition.

In June 1995, the IEEE Standards Board approved the establishment of “Standards Coordinating Committee 34 (SCC34), Product Performance Standards Relative to the Safe Use of Electromagnetic Energy.” Standards developed by SCC34 do not specify limits for human exposure to electromagnetic fields, but refer to established limits found in science-based standards such as IEEE Std C95.1™-2005, IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz.

In 2005, SCC28 and SCC34 became “Technical Committee 95” and “Technical Committee 34,” respectively, under a new IEEE Standards Coordinating Committee, SCC39, which is now called “ICES.”¹

The present scope of IEEE ICES Technical Committee 95 (TC95) is as follows:

“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 ICES.”

There are six TC95 Subcommittees, each of whose area of responsibility is described as follows in correspondence with its designated Subcommittee number:

- SC 1: Techniques, Procedures, Instrumentation, and Computation
- SC 2: Terminology, Units of Measurements, and Hazard Communication
- SC 3: Safety Levels with Respect to Human Exposure, 0 Hz to 3 kHz
- SC 4: Safety Levels with Respect to Human Exposure, 3 kHz to 300 GHz
- SC 5: Safety Levels with Respect to Electro-Explosive Devices
- SC 6: EMF Modeling and Dosimetry

¹ Standards Coordinating Committees are established by the IEEE SA Standards Board and provide a mechanism to oversee the development of standards that are beyond the scopes of individual technical committees within IEEE’s societies.

This standard was prepared by Subcommittee 3 and Subcommittee 4 of TC95. TC95 has issued three standards, four recommended practices, and one guide. The present versions are as follows:

- IEEE Std C95.1™-2019, IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz.
- IEEE Std C95.1-2345™-2014, IEEE Standard for Military Workplaces—Force Health Protection Regarding Personnel Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz.
- IEEE Std C95.2™-2018, IEEE Standard for Radio-Frequency Energy and Current-Flow Symbols.
- IEEE Std C95.3™-2002 (R2008), IEEE Recommended Practice for Measurements and Computations of Electric, Magnetic, and Electromagnetic Fields With Respect to Human Exposure to Such Fields, 100 kHz to 300 GHz.
- IEEE Std C95.3.1™-2010, IEEE Recommended Practice for Measurements and Computations of Electric, Magnetic, and Electromagnetic Fields with Respect to Human Exposure to Such Fields, 0 Hz to 100 kHz.
- IEEE Std C95.4™-2002 (R2008), IEEE Recommended Practice for Determining Safe Distances from Radio Frequency Transmitting Antennas When Using Electric Blasting Caps During Explosive Operations.
- IEEE Std C95.7™-2014, IEEE Recommended Practice for Radio Frequency Safety Programs, 3 kHz to 300 GHz.²
- IEEE Std 1460™-1996 (R2008), IEEE Guide for the Measurement of Quasi-Static Magnetic and Electric Fields.

Dedication

This edition of IEEE Std C95.1 is dedicated in memory of Ronald C. (Ron) Petersen. Ron served on various IEEE committees beginning in the 1970s, particularly SCC28, SCC34, and SCC39 (ICES). He also served as chair of the International Electrotechnical Commission (IEC) TC 106 (EMF exposure) through its first 15 years. Ron's passing represents a great loss for the IEEE, and especially for ICES. His constant attention to the workings of this committee and the development of standards documents formed the glue that ensured the continued cohesiveness and success of ICES. We will all miss Ron in our meetings—he lives forever in our memories.

² The latest revisions of IEEE Std C95.1, IEEE Std C95.1-2345, IEEE Std C95.2, IEEE Std C95.3, IEEE Std C95.3.1, and IEEE Std C95.7 are available at no cost (at the time of publication of this standard) through the IEEE Get Program. (<https://ieeexplore.ieee.org/browse/standards/get-program/page/series?id=82>).

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IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and ~~Radio-Frequency~~ Electromagnetic Fields, 0 Hz ~~3 kHz~~ to 300 GHz

1. Overview

1.1 Scope

This standard specifies exposure criteria and limits ~~Recommendations are made~~ to protect against established adverse health effects in humans ~~human beings~~ associated with exposure to electric, magnetic, and electromagnetic fields in the frequency range of 0 Hz ~~3 kHz~~ to 300 GHz. ^{1,2} These limits, incorporating safety margins, ~~The recommendations~~ are expressed in terms of dosimetric reference limits ~~basic restrictions~~ (DRL BRs) and ~~maximum permissible~~ exposure reference levels (ERL). ~~DRLs (MPE) values. The BRs are expressed in terms of in situ electric field strength limits on internal fields,~~ specific absorption rate (SAR), and epithelial power ~~current~~ density. ERLs ~~the MPEs,~~ which are more easily determined ~~derived from the BRs,~~ are limits on external electric and magnetic fields, incident power density, and induced and contact currents, and contact voltages intended to ensure that the DRLs are not exceeded. The limits ~~current. The recommendations,~~ which protect against adverse health effects associated with electrostimulation of ~~and~~ tissue and local and whole-body heating, are intended to apply to the described human exposure conditions. However, these levels are not intended to address all human exposures except for exposure of patients by, or human research subjects under the care of direction of, physicians and medical professionals for which other risks and benefits might apply. These exposure limits might not prevent ~~These recommendations are not intended for the purpose of preventing~~ interference with medical and other devices that might ~~may~~ exhibit susceptibility to electromagnetic interference (EMI), radio frequency (RF) fields. The recommendations at 300 GHz are compatible with existing recommendations for safe exposure in the infrared frequency range, which begins at 300 GHz, cf., ANSI Z136.1-2000 [B7]¹, ICNIRP guidelines [B63], and IEC 60825-1 [B65]. IEEE Std C95.6-2002² is the applicable standard for use at frequencies below 3 kHz.

1.2 Purpose

The purpose of this standard is to provide science-based exposure criteria limits to protect against established adverse health effects in humans associated with ~~to human health induced by~~ exposure to ~~RF~~ electric, magnetic, and electromagnetic fields; induced and contact currents; and contact voltages, over the frequency range of 0 Hz ~~3 kHz~~ to 300 GHz.³

1.3 General introduction

1.3.1 General

This standard is a revision and merging of IEEE Std C95.1™-2005 [B668] and IEEE Std C95.6™-2002 [B671].⁴ Updated information is also included from IEEE Std C95.1-2345™-2014 [B669] (military workplaces and personnel protection), which preceded this standard in combining and updating IEEE Std C95.1-2005 and IEEE Std C95.6-2002, introduced expanded frequency-dependent exposure levels for contact currents, and introduced new terminology such as “safety program initiation level” and “unrestricted” and “restricted environments.” Recommendations to protect against established adverse health effects to humans from exposures to electric fields, magnetic fields, electromagnetic fields, and contact currents are defined on the basis of a comprehensive review of the scientific literature.

¹ The limits in this standard are intended to protect against adverse health effects except in certain cases of contact current exposures or RF arcing exposures that could result in highly localized burns or transient adverse reactions (e.g., startle or pain).

² The limits at 300 GHz for persons permitted in restricted environments are the same as the corresponding values in existing standards for exposure in the infrared frequency range, which begins at 300 GHz (cf. ANSI Z136.1-2014 [B69] and IEC 60825-1 [B653]).

³ The frequencies and wavelengths covered by this standard are in the “nonionizing radiation” region of the electromagnetic spectrum.

⁴ The numbers in brackets correspond to those of the bibliography in Annex E.

The literature review conducted for IEEE Std C95.1-2005 remains as a strong foundation for the present standard (see C.2 to C.7). As discussed in A.1.7, the International Committee on Electromagnetic Safety (ICES) literature review working group (LRWG) found that many recent health agency and expert group reviews confirm the protectiveness of the existing limits; the major changes in limits in this standard are the DRLs and ERLs above 6 GHz based on recent thermal modeling studies. Detailed reviews of scientific studies dealing with effects at frequencies above 6 GHz are included in C.8. Review of the extensive literature on electromagnetic field (EMF) biological effects revealed that electrostimulation is the dominant effect at low frequencies and that thermal effects dominate at high frequencies. Examination of the radio frequency (RF) exposure literature revealed no reproducible low-level (nonthermal) adverse health effects. Moreover, the scientific consensus is that there are no accepted theoretical mechanisms that would explain the existence of low-level adverse health effects. Since the publication of ANSI C95.1-1982 [B68], advances have been made in the scientific knowledge of the biological effects of exposure to electromagnetic energy. This additional and cumulative knowledge helps strengthen the basis for and confidence in the assertion that the ERLs and DRLs in this standard are protective against established adverse health effects.

1.3 Introduction

~~This standard is a revision of IEEE Std C95.1, 1999 Edition [B70] and IEEE Std C95.1b-2004 [B71]. The recommendations to protect against established adverse health effects from RF exposures have been made on the basis of a comprehensive review of the scientific data. In revising the standard, findings of studies published between 1950 and December 2003³ were considered, including those studies that involve low level exposures where increases in temperature could not be measured or were not expected. New insights gained from improved experimental and numerical methods and a better understanding of the effects of acute and chronic RF electromagnetic field exposures of animals and humans are included. A lack of credible scientific and medical reports showing adverse health effects for RF exposures at or below similar exposure limits in past standards supports the protective nature of the exposure limits. This standard includes guidance on the necessity of an RF safety program.~~

Based on the results of the latest ICES LRWG literature review, relevant mechanisms of interaction were found to be stimulation of excitable nervous tissue by electric fields induced within the body due to electric and/or magnetic fields and produced by contact current (frequencies between 0 Hz and approximately 5 MHz),⁵ as well as by tissue heating (frequencies above approximately 100 kHz). In the transition region of 100 kHz to 5 MHz, the more restrictive of the two limits apply; generally: 1) ERLs associated with heating are more restrictive for long-term exposures (i.e., greater than the averaging time) to continuous-wave (CW) fields, and 2) ERLs based on electrostimulation are. This standard presents two separate sets of rules to limit human exposure to electric fields, magnetic fields, and electromagnetic fields, and to induced and contact currents, in order to protect against established adverse health effects identified in the reviewed studies that are associated with exposure to such fields and currents. Specifically, in the frequency range of 3 kHz to 5 MHz, the rules minimize adverse effects associated with electrostimulation; in the frequency range of 100 kHz to 300 GHz, the rules protect against adverse health effects associated with heating. In the transition region of 0.1 to 5 MHz, each of the two sets of rules must be applied. In this transition region the rules based on heating will be more restrictive for long-term exposures to continuous wave (CW) fields, while the rules based on the effects of electrostimulation will be more restrictive for short-term exposure (e.g., short isolated pulses of low duty factor).

The whole-body average (WBA) DRLs rules and ERLs the exposure limits incorporate conservative safety factors that take into account biological and dosimetry for uncertainties in laboratory studies and the variability of response thresholds within the human population, and that provide a margin of safety for all. (See B.1.3 Annex C.6 for the derivation and detailed aspects of the safety factors.) The safety factors are conservative so that exposures that exceed the BR or MPE are not necessarily harmful. The safety factors incorporated in the MPEs are generally greater than the safety factors in the BRs. Thus, it is possible to exceed an ERL MPE while still complying with the DRL. While numerous refinements are described in this document, a fundamental aspect of this standard is that it continues to support the findings of earlier editions BRs.

⁵ The effects associated with electrostimulation are categorized as short-term effects.

The following short-term reactions associated with electrostimulation at frequencies below 100 kHz for CW exposures have been established: 1) aversive or painful stimulation of sensory or motor neurons; 2) muscle excitation that can lead to injury while performing potentially hazardous activities; 3) excitation of neurons or direct alteration of synaptic activity within the brain; 4) cardiac excitation; and 5) adverse health effects associated with induced potentials or forces on rapidly moving charges within the body, such as in blood flow. These findings are consistent with the conclusions of interdisciplinary panels of scientists that have evaluated the literature on exposures to electric and magnetic fields for scientific and governmental organizations through 2017 (see C.1). Data from studies published between 1901 and 2017 were considered for frequencies below 100 kHz, including those studies that involve exposures below electrostimulation thresholds.

For frequencies between 100 kHz and 300 GHz, tissue heating and whole-body heating predominate. The most sensitive reproducible effect is disruption of food-motivated behavior in animal species, ranging from rodents to primates and over a wide range of frequencies. These findings are consistent with those of interdisciplinary panels of scientists from scientific and governmental organizations that have evaluated the literature, including chronic (long-term) exposure studies (see Annex C). Data from studies published between 1948 and December 2017 were considered for frequencies from 6 GHz to 300 GHz, including those studies that involve low-level exposures where increases in temperature could not be measured or were not expected.⁶

The previous standard IEEE Std C95.1-2005 [B668] contained two exposure tiers: 1) an upper tier for “people in controlled environments,” and 2) a lower tier designated an “action level.”~~The values of the electric and magnetic field strength, the incident power density, contact and induced current, and contact voltages~~ above which steps should be initiated to protect against exposures that exceed the upper tier ~~(specifically, implementation of an RF safety program).~~ The upper boundary of the lower tier was considered to be an exposure limit for the general public.

^{6,3} Although the literature review cutoff date of IEEE Std C95.1-2005 [B668] was December 2003, several papers published in 2004 and 2005 were included thereunder. While review of the 2003 to 2017 high-frequency literature remains ongoing, the review findings used for this revision cover the literature for frequencies above 6 GHz to address the corresponding changes in the exposure limits between 6 GHz and 300 GHz.

Various new definitions are introduced in this standard. The terms unrestricted tier (lower tier) and restricted tier (upper tier) refer to ranges of permissible exposure values, with each tier having an upper limit.⁷ The lower tier limit is designated as the “safety program initiation level” (rather than as the “action level”) to emphasize that an RF safety program is necessary. It should be noted that in this standard, the upper tier exposure limit is referred to as applicable to “persons permitted in restricted environments,” to emphasize that individuals might occupy restricted environments, where the higher ERLs and DRLs are applicable, if those individuals follow the applicable safety program guidance and procedures. This standard specifically avoids the declaration that only individuals who are exposed because of their occupation may enter restricted environments. For portable devices, such as mobile phones and professional two-way radios, the lower tier DRL is applicable to devices available to the general public. The higher tier DRL is applicable to devices for which user awareness information/training is provided.

The literature review also evaluated the possibility of adverse health effects associated with chronic low-level exposure. For exposures to electric, magnetic, and electromagnetic fields at frequencies between 0 Hz and 300 GHz, the following two conclusions were reached:

- a) The weight-of-evidence provides no credible indication of adverse effects caused by chronic exposures below levels specified in this standard.

⁷ In this standard, the terms “upper tier” and “lower tier” are used interchangeably with “restricted tier” and “unrestricted tier,” respectively.

b) No biophysical mechanisms have been scientifically validated that would link chronic exposures below levels specified in this standard to adverse health effects.⁸

⁸ ICES TC95 is aware of epidemiological studies and reviews that have reported positive associations between cancer and electromagnetic fields in both the ELF and RF frequency ranges. The World Health Organization (WHO), in analyzing the 2002 International Agency for Research on Cancer (IARC) evaluation of exposure to ELF magnetic fields came to the following conclusion: “Thus, on balance, the evidence related to childhood leukaemia is not strong enough to be considered causal” (WHO [B1496] and WHO/IARC [B1501]). At higher frequencies, most epidemiologic studies have addressed the reported association of adult brain cancer with inferred RF exposure from the use of mobile telephones. The preponderance of epidemiologic evidence does not provide a sufficient basis for concluding that adult brain cancer is positively associated with mobile telephone use and, by implication, with RF exposures. IARC classified RF electromagnetic fields as a possible human carcinogen (Group 2B) in its classification system (Baan et al. [B93]). After this IARC classification, WHO issued a revised fact sheet 193 (WHO [B1494]) indicating that, “A large number of studies have been performed over the last two decades to assess whether mobile phones pose a potential health risk. To date, no adverse health effects have been established as being caused by mobile phone use.” Furthermore, WHO also indicated that, “IARC has classified radiofrequency electromagnetic fields as possibly carcinogenic to humans (Group 2B), a category used when a causal association is considered credible, but when chance, bias or confounding cannot be ruled out with reasonable confidence.” The *[Footnote 8 continued from previous page]* International Commission on Non-Ionizing Radiation Protection (ICNIRP) Standing

Committee on Epidemiology also published an epidemiology review to conclude that, “Although there remains some uncertainty, the trend in the accumulating evidence is increasingly against the hypothesis that mobile phone use can cause brain tumours in adults” (ICNIRP [B650]).

In both frequency ranges, cancer bioassays in rodents have been predominantly negative (no persuasive evidence of effects have been found at the exposure levels permitted in the standard). Furthermore, no plausible biophysical mechanisms have been verified that explain hypothesized adverse effects at low-level exposures. Thus, ICES concludes that only the established acute mechanisms related to electrostimulation between 0 Hz and 100 kHz (and up to 5 MHz for exposures to pulses) and tissue heating between 100 kHz and 300 GHz need to be addressed to provide a valid basis for the DRLs and ERLs designated in this standard.

ICES is also aware of the U.S. National Toxicology Program’s draft study reports and peer-review outcomes on the effects of Global System for Mobile Communications (GSM) and Code Division Multiple Access (CDMA) RF signals on whole-body exposure of rats and mice at levels that exceed the DRLs in this standard. The NTP studies were conducted for the purpose of hazard identification. As is the continuing practice of ICES, the final NTP reports and subsequent evaluations and risk assessments by other organizations will be addressed in future revisions of the standard. A careful assessment of the NTP study by ICNIRP describes several difficulties in interpreting the results of the study for development of standards, in particular, the use of exposure levels in the NTP study that were considerably above the existing or proposed whole-body exposure limits of IEEE Std C95.1; “ICNIRP NOTE on recent animal carcinogenesis studies,” Sep. 4, 2018 (<https://www.icnirp.org/cms/upload/publications/ICNIRPnote2018.pdf>).

Based on the collective findings of recent reviews, the weight of the evidence continues to indicate that chronic exposure at levels specified in this standard is unlikely to cause adverse health effects. The ICES Subcommittees will continue to evaluate new research and will, if appropriate, initiate revision of this standard.

~~Two tiers of exposure limits have been established. The upper tier, which is protective for all with an acceptable margin of safety, applies to exposure of persons in controlled environments. While the weight of scientific evidence supports the conclusion that there is no measurable risk associated with RF exposures below the upper tier of this standard, it is scientifically impossible to prove absolute safety (the null hypothesis) of any physical agent. Thus the lower tier, with an additional safety factor, recognizes public concerns and also supports the process of harmonization with other standards, e.g., the NCRP recommendations [B95] and the ICNIRP guidelines [B62]. The lower tier also defines the action level above which implementation of an RF safety program is recommended. The BRs and MPEs of the lower tier may also be used for the general public to address concerns of continuous, long term exposure of all individuals.~~

1.3.2 Protected population

This standard is ~~These exposure limits are~~ intended to apply to all people, with the exception of patients undergoing procedures ~~a procedure~~ for medical diagnosis or treatment that requires exposure to fields or current in excess of the DRLs and ERLs of this standard. This exemption is provided under the expectation that the medical staff is appropriately trained in minimizing the risk ~~of RF hazards~~ concomitant with the provision of a recognized benefit from the exposure. Likewise, this standard does not apply to exposure of informed volunteers in medical or scientific research studies, such as those subject to approval by institutional review boards for the use of human subjects, nor is it intended to prevent interference with medical and other devices that can ~~may~~ exhibit susceptibility to EMI.⁹ ~~to RF energy~~⁴.

^{9,4} While the issue of RF emissions from wireless transmitters causing electromagnetic interference (~~EMI~~) with medical devices is outside the scope of the current standard, the reader is directed to ~~there are~~ several relevant standards that ~~the reader is directed to~~ ~~that~~ recommend immunity levels for external medical devices (e.g., IEC 60601-1 [B65] ~~B66~~] and IEC 60601-1-2 [B62] ~~B67~~], as well as implantable medical devices (e.g., ANSI/AAMI PC69:2007 [B71] ~~and 2000 [B5]~~; ISO/TR 21730:2007 [B69] ~~offer TC215 Technical Report 21073 [B75] offers~~ guidance for the use and operation of mobile wireless transmitters within healthcare facilities).

Application of this standard is intended to offer protection to all persons in unrestricted exposure environments such as living quarters, public areas, and workplaces (unrestricted tier), as well as to persons permitted in restricted environments (restricted tier). DRLs and ERLs recommended in this standard are intended to protect against established adverse effects. Examples of exposure mitigation include engineering controls (engineering controls are the preferred approach to exposure mitigation in most exposure scenarios), administrative controls, personal protective equipment (PPE) such as insulative gloves and/or protective clothing, awareness programs, and operator training documentation designed to alert personnel to the possibility of effects, or specific work practices that lessen the duration or intensity of exposure (e.g., per IEEE Std C95.7™).¹⁰

1.3.3 Safety factors

1.3.3.1 General

Safety factors and their rationales are different for frequencies below approximately 100 kHz (but possibly up to 5 MHz for pulsed fields), where the adverse effect being minimized is electrostimulation, and above 100 kHz where the adverse effects being protected against are related to tissue heating.¹¹ In the transition region of 100 kHz to 5 MHz, both electrostimulation and heating can occur. For frequencies above 6 GHz, the safety factors apply to the square of amplitudes of the *in situ* or incident fields. the effect being protected against is tissue surface heating. The three types of effects (i.e., electrostimulation, whole-body heating, and local heating) are protected against through three separate sets of DRLs and ERLs that are applicable within the respective frequency ranges, as described in 1.3.3.2 through 1.3.3.4.

¹⁰²Information on references can be found in Clause 2.

¹¹ At low frequencies, safety factors apply to the amplitude of the *in situ* field; at high frequencies, the safety factors apply to the square of amplitudes of the *in situ* or incident fields.

1.3.3.2 Frequencies below 100 kHz (5 MHz for pulsed fields)

1.3.1 Safety factor and margin of safety

~~Below 100 kHz, the effect being minimized is aversive or painful electrostimulation.~~ Because the predominant interaction mechanisms are different above and below approximately 100 kHz (5 MHz for certain pulsed fields), the nature of and the rationale for the safety factors differ. Below 100 kHz, this standard protects against aversive or painful effects associated with ~~At low frequencies,~~ electrostimulation, which has a characteristic response time that is much less than 1 s ~~one-second~~ and exposures are thus assessed in terms of instantaneous fields or currents. DRLs for electrostimulation include upper and lower tier safety factors (divisors, designated as SFU and SFL) that are applied to a median adverse-reaction threshold. The value of SFU , which is 3 for all tissues, protects against adverse reactions for all but a small segment of the population ($< 1\%$). The value SFL is 3 for the limbs and 9 for other tissues, thus, providing an additional margin to further reduce the probability of adverse response in exposed individuals not covered by SFU . For the restricted tier, $SFU = 3$ is applied to all tissues including brain tissue and neural tissue within the trunk, based on the following observations: ~~The estimated safety factor in terms of currents or fields is between 3 and 10 (10–20 dB) in the worst case even though for many situations and people the safety factor is considerably greater. An upper tier, which is applicable to exposures in controlled environments, incorporates a smaller safety factor approaching a minimum of unity, even though in most cases the safety factor is considerably greater. A margin of safety near unity, equivalent to no margin of safety, is justified for the upper tier MPEs below 100 kHz for the following reasons: a) the maximum-~~

- a) An adverse reaction for sensory perception at the upper tier of the DRL would be expected to occur in no more than 1 % of persons permitted in restricted environments and with no credible possibility of cardiac arrhythmias.
- b) Electrostimulation that might occur at the upper tier limit has no lasting adverse health effect, ~~b) the requirement of an RF safety program, and c) the general awareness of workers in occupational situations. A greater margin of safety is provided in the lower tier for frequencies below 100 kHz.~~

c) A safety program is required when exposures are anticipated above the lower tier ERL.

d) Workers in occupational situations (persons permitted in restricted environments) can be made aware of the potential for adverse reactions and mitigation measures.

1.3.3.3 Frequencies between 100 kHz and 6 GHz

Above 100 kHz, the effect associated with exposure to CW fields transitions from electrostimulation to tissue heating, and ~~there can be a sensation of heating, which is not considered adverse. The limits in this standard may not prevent such thermal sensations; they are designed to protect against adverse health effects resulting from tissue heating, the only established adverse effect of exposure to RF energy at frequencies above 100 kHz.~~ Above 100 kHz, exposures are assessed with reference to an averaging time that varies in accordance with whole-body or local exposure. ~~with frequency and at some frequencies depends on the tier designation (action level and controlled environment).~~ The frequency 100 kHz nominally represents a “thermal crossover” below which electrostimulation effects dominate, and above which thermal effects dominate for CW ~~continuous-wave~~ exposure. However, for pulsed waveforms, especially those of a low duty factor, the upper frequency at which electrostimulation has been demonstrated reaches 5 MHz. ~~thermal crossover can extend to much higher frequencies (in the megahertz region).~~ This standard contains criteria to protect against adverse electrostimulation effects for pulsed waveforms with ~~having~~ fundamental frequencies above 100 kHz.

For short-duration exposures (less than the averaging time) at frequencies above 100 kHz, the DRLs ~~BRs~~ and ERLs associated with tissue heating ~~MPEs~~ are related to energy (i.e., specific absorption (SA) or incident energy density). It is possible, however, to continue to use the DRLs ~~BRs~~ and ERLs ~~MPEs~~ expressed in power terms (i.e., SAR), ~~or, specific absorption rate (power density, or equivalent fields),~~ recognizing their time dependence. In this case the ~~adverse~~ effect to be protected against includes ~~is~~ tissue damage that can result from excessive RF heating or from potentially adverse behavioral effects consequent to heating.

For long-duration exposure (equal to or ~~durations considerably~~ greater than the averaging time), the ERLs are effect to be protected against is that shown to be the most sensitive to RF exposure, behavioral disruption observed in animals and extrapolated from the exposure levels and SARs from laboratory studies of nonhuman species, specifically, exposure levels and SARs that resulted in a behavioral disruption response. Behavioral disruption is considered to be the most sensitive reproducible response to RF exposure indicative of a potential adverse health effect (D'Andrea et al. [B313]). This process results in conservative DRLs and ERLs because of the superior thermoregulatory capacity of humans compared with laboratory animals ~~to humans~~.

The safety factors for both whole-body and local exposures have ~~exposure durations greater than the averaging time has~~ been estimated to be approximately 10 and 50 or more in terms of SAR or power density ~~be in the range of 10 to 50 in power (10 to 17 dB)~~ for the upper tier and lower tier respectively. (See B.4 and B., ~~i.e., an additional~~ 7.6 for discussions of safety factors.) ~~dB~~. The safety factors for special exposure measures, such as local exposures, peak (short pulse) limits, and contact and induced currents in the limbs, are also ~~often related to the safety factors incorporated in the BRs or MPEs for fields. This factor is generally~~ of the order of 5 to 10 above 100 kHz. The margin of safety for the DRLs and ERLs is generally greater for whole-body exposure in the resonance region than for local exposures ~~at least 10 dB~~.

Recently published research results have helped to provide a quantitative perspective on the magnitude of these safety factors (Adibzadeh et al. [B34]). This research in which RF energy absorption rates have been compared to tissue-damaging temperatures has estimated that the arbitrary safety factor of 10 used for the upper tier exposure limits in this standard translates to actual values between 10.9 and 31.2 depending on the target size of the exposed tissue, averaging times, and the degree of perfusion of the tissue of concern.

For local exposure at frequencies where SAR is applicable, the averaging mass for peak spatial-average SAR (psSAR) is 10 g of tissue defined as a tissue volume in the shape of a cube. The averaging volume of 10 g of tissue would be represented as a cube with a volume of approximately 10 cm³, or about 2.15 cm per side. At 3 GHz, the penetration depth of the field in high-water-content tissues is about 1.6 cm, which is smaller than the depth of the averaging volume. To harmonize with the new ICNIRP RF Guidelines,¹² the frequency range over which the DRL is expressed in terms of SAR has been extended to 6 GHz.

1.3.2 RF risk assessment and RF safety programs

~~Throughout the RF spectrum to which this standard is applicable, the MPEs apply to exposure of individuals. Areas wherein intense RF fields exist (that exceed the MPEs) would be an exposure issue only when individuals have access to those areas and may become exposed. Hence, compliance with this standard is to be determined by assessing whether persons may be exposed to RF fields exceeding the MPEs and not necessarily by whether RF fields simply exceed the MPEs. This standard recommends that when and where there may be access to RF fields, currents, and/or voltages that exceed the lower tier MPEs (action levels), exposures are to be controlled through the implementation of an RF safety program, as described in IEEE Std C95.7-2005. Application of an RF safety program results in various control measures that can be taken to reduce the probability of a person's exposure exceeding the BRs and MPEs of the upper tier.~~

¹² The draft of the ICNIRP Guidelines on Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields (100 kHz to 300 GHz) was published for public consultation in July 2018 (<https://www.icnirp.org/en/activities/public-consultation/consultation-1.html>).

1.3.3.4 Frequencies above 6 GHz

For frequencies above 6 GHz, the effect being protected against is excessive RF heating—primarily surface heating causing a sense of prickling pain on the skin or eyes and possibly leading to tissue damage (burns). Because the heated layer of tissue is thin, the thermal time constant is considered to be short and heating can be rapid. However, heat is conducted into surrounding structures and the temperature rise is limited unless the exposure is prolonged. Also, the smaller the area of exposure, the greater the capacity of tissue to disperse localized heating, thereby reducing the thermal impact of intense exposure.

The body has an efficient thermoregulatory system that is designed to protect the body from sizeable variations in environmental temperature and thermal load due to exercise. Consequently, the DRLs (in terms of epithelial power density) and ERLs (incident power density) are very conservative for whole-body exposures. For whole-body exposures over the entire 6 GHz to 300 GHz range, the safety factor for whole-body exposure (relative to excessive thermal load on the body) in ordinary room environments is more than 10, and for persons in unrestricted areas, it ranges from more than 10 to more than 100. While the safety factors are smaller for individuals in very warm environments, the effect of RF heating of the body at the ERL for the upper tier is far outweighed by effects due to ambient temperature and relative humidity and the type of clothing worn. Consequently, the limits are considered to be sufficiently protective even for individuals in warm environments. In all cases, the safety factors for unrestricted environments are five times greater than those for restricted environments (Moore et al. [B1035]).

1.3.4 Risk assessment and safety programs

A safety program, such as described in IEEE Std C95.7, shall be implemented whenever the lower tier DRLs (or corresponding ERLs) can be exceeded (safety program initiation level). For persons in unrestricted environments, the lower tier DRLs shall not be exceeded. For persons permitted in restricted environments, the lower tier DRLs may be exceeded but the upper tier DRLs shall not be exceeded. The identification of restricted environments is accomplished via an exposure assessment. Any resulting RF safety program shall implement appropriate controls for access to the restricted environment. The purpose of the safety program is to prevent exposures that exceed the upper tier exposure limits. While safety programs are applied to fixed (or stationary) sources of electromagnetic fields, portable devices such as mobile phones or professional two-way radios are subject to separate requirements for limiting psSAR in tissues. Manufacturers shall provide procedures to assure compliance with respect to the DRLs for either lower or upper exposure tiers as appropriate.

1.4 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (shall equals is required to).^{13,14}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (should equals is recommended that).

The word *may* is used to indicate a course of action permissible within the limits of the standard (may equals is permitted to).

¹³ The use of the word *must* is deprecated and shall not be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

¹⁴ The use of *will* is deprecated and shall not be used when stating mandatory requirements, *will* is only used in statements of fact.

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (can equals is able to).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std C95.3-~~2002~~TM, IEEE Recommended Practice for Measurements and Computations of Radio Frequency Electromagnetic Fields with Respect to Human Exposure to Such Fields, 100 kHz–300 GHz. 15, 16 ~~5, 6~~

IEEE Std C95.3.16TM-~~2002~~, IEEE Recommended Practice for Measurements and Computations of Electric, Magnetic, and Electromagnetic Fields ~~Standard for Safety Levels~~ with Respect to Human Exposure to Such ~~Electromagnetic~~ Fields, 0 Hz to 100 ~~3~~ kHz.

IEEE Std C95.7-~~2005~~TM, IEEE Recommended Practice for Radio Frequency Safety Programs, 3 kHz to 300 GHz.

¹⁵ IEEE 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/>).

¹⁶ The IEEE standards or products referred to in ~~this~~-Clause 2 are trademarks owned by ~~of~~ the Institute of Electrical and Electronics Engineers, Incorporated ~~Ine~~.

3. Definitions, acronyms, abbreviations, and ~~letter~~ symbols

3.1 Definitions

For the purposes of this document ~~standard~~, the following terms and definitions apply. The ~~Authoritative Dictionary of IEEE Standards~~ Dictionary Online Terms [B72], should be consulted ~~referenced~~ for terms not defined in this clause. ¹⁷~~For the convenience of the reader, terms used in this standard that are defined in The Authoritative Dictionary of IEEE Standards Terms are contained in a glossary (see Annex E).~~

action level: Deprecated. See: safety program initiation level.

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

adverse health effect: An effect detrimental to an individual's physical well-being due to exposure to an electric, magnetic, or electromagnetic field or to induced or contact currents or voltages. For purposes of this standard, adverse effect is interchangeable with adverse health effect or adverse reaction. ~~A biological effect characterized by a harmful change in health.~~ See also: **established adverse health effect.**

NOTE 1—Adverse effects do not include biological effects without a harmful health effect or, changes in subjective feelings of well-being.¹⁸ ~~that are a result of anxiety about RF effects or impacts of RF infrastructure that are not physically related to RF emissions, or indirect effects caused by electromagnetic interference with electronic devices.~~

¹⁷IEEE Standards Dictionary Online is available at: <http://dictionary.ieee.org>.

¹⁸Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

NOTE 2— Sensory Sensations (perceptions ~~by human sense organs~~) *per se* are not necessarily considered adverse health effects. For example, Thus a perception sensation of warmth at millimeter and other wavelengths and the microwave auditory effect under the underlying special conditions are not recognized as effects to be protected against by this standard.

NOTE 3—Painful or aversive sensations are considered adverse~~electrostimulation resulting from exposure at frequencies below 0.1 MHz is treated as an adverse effect.~~

adverse health effect exposure level: The magnitude and/or duration of an exposure that can produce an adverse health effect.

adverse reaction factor (FA): For electrostimulation effects, a multiplier ≥ 1 used to convert a median threshold for a biological effect up to the median level that makes this effect adverse.

arc: A conductive channel of ionized gas formed in the gap between two electrodes when the potential gradient is sufficient to cause dielectric breakdown of the insulating medium (e.g., air) between the electrodes.

~~3.1.3 adverse effects exposure level~~: The condition or set of conditions under which exposure to an electric, magnetic, or electromagnetic field can produce a harmful change in health. Conditions can be a property of the source (such as field strength, polarization, power density, frequency, modulation, pulse duration and repetition frequency), a dosimetric quantity (such as current, current density, specific absorption, or specific absorption rate), and an exposure characteristic (such as exposure duration and recurrence interval). This standard is based on the lowest known exposure levels for all established adverse effects. The maximum permissible exposure (MPE) values in this standard are derived from these exposure levels incorporating appropriate margins of safety.

average (temporal) power ($\bar{P}$): The time-averaged rate of energy transfer.

NOTE 1—The SI unit of average (temporal) power is ~~the~~ watt (W).

NOTE 2—Average temporal power is expressed as

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

where $P(t)$ is the instantaneous power. ~~NOTE~~—The time duration ($t_2 - t_1$) could be source related (e.g., the [waveform](#) ~~source~~ repetition period ~~or~~ duty [factor](#) ~~cycle~~) or use related [~~e.g., the averaging time associated with the specified-in~~ exposure [reference level \(ERL guidelines\)](#)].

average (temporal) power density: The ~~instantaneous~~ power density [in a propagating wave integrated \(averaged\)](#) over a specific time duration. ~~The time duration could be source related, e.g., the source repetition period, or use related, e.g., the averaging time specified in exposure guidelines.~~

NOTE 1—The SI unit of average [\(temporal\)](#) power density is ~~the~~ watt per square meter (W/m^2).

NOTE 2—The time duration could be source related (e.g., the waveform repetition period) or use related [~~e.g., the averaging time associated with the exposure reference level (ERL)~~].

averaging area: The area over which a physical quantity is averaged for assessing compliance.

NOTE—For compliance with the ERLs, the averaging area is the area over which the power density is averaged when the frequency is greater than 100 MHz, and the area over which the field strength squared is averaged when the frequency is between 100 kHz and 100 MHz. For frequencies below 100 kHz, see [averaging distance](#).

averaging distance: The distance over which the *in situ* electric field is averaged when determining compliance with [a dosimetric reference limit \(DRL\) for electrostimulation](#) ~~basic restrictions~~.

averaging mass: The mass over which the specific absorption rate is averaged when determining compliance with a dosimetric reference limit (DRL).

averaging time (T_{avg}): The appropriate time period over which exposure is averaged for purposes of determining compliance with [the appropriate](#) ~~a maximum permissible~~ exposure (~~MPE~~) ~~or~~ reference level ([ERL](#)) or dosimetric reference limit (DRL).

~~NOTE—Averaging time T_{avg} has an unambiguous meaning only at frequencies above 0.1 MHz, i.e., for the MPEs relating to heating effects. For an exposure time greater than T_{avg} , the MPE is an entity expressed in power units, e.g., SAR or power density, or in terms of field units, while for an exposure time smaller than T_{avg} , the MPE can be expressed as a power or field function of time or an equivalent integral quantity, e.g., specific absorption or energy density either on a volume or area basis.~~

averaging volume: The volume over which the ~~peak-spatial-average~~ specific absorption rate is averaged when determining compliance with a dosimetric reference limit (DRL) ~~the basic restrictions~~.

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

axial exposure: Exposure by an electric, magnetic or electromagnetic field perpendicular to the axial cross section.

axon: The long extension of a neuron that conducts electrical impulses.

~~**3.1.9 basic restrictions:** Exposure restrictions that are based on established adverse health effects that incorporate appropriate safety factors and are expressed in terms of the *in situ* electric field (3 kHz to 5 MHz), specific absorption rate (100 kHz to 3 GHz), or incident power density (3 GHz to 300 GHz).~~

biological effect: A biological effect ~~is an established effect~~ caused by, or in response to, exposure to a biological, chemical, or physical agent, including electromagnetic energy.

NOTE 1—Biological effects are alterations of the structure, metabolism, or functions of a whole organism, its organs, tissues, and cells.

NOTE 2—Biological effects can occur without ~~adverse~~ ~~harming~~ health ~~effects or even~~ ~~and can~~ be beneficial; they can also cause harm in the short term (e.g., heating, without long-term consequences).

NOTE 3—Biological effects also can include sensation phenomena and adaptive responses.

biphasic: A waveform characteristic involving a reversal of polarity.

cardiac excitation: The electrical stimulation of a cardiac contraction.

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

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

chronic exposure: A sequence of many repeated or continuous exposures over a long period of time (e.g., months to years, depending on the biological species ~~system~~ being considered and its lifespan).

conductivity: A property of materials that determines the magnitude of the electric current density when an electric field is impressed on the material.

NOTE—The SI unit of conductivity is siemens per meter (S/m); the inverse of resistivity.

~~3.1.12 confirmed adverse health effect: See: established adverse health effect.~~

~~3.1.13 confirmed effect: See: established effect.~~

contact current: The current flowing through a person contacting charged conducting objects
~~Current induced in a biological medium via a contacting electrode or other source of current.~~

NOTE—Contact current is specified as either that associated with a grasping contact (area assumed to be 15 cm²) or a touch contact (area assumed to be 1 cm²).

contact voltage: For purposes of this standard, an open-circuit voltage between two conducting objects that when bridged by a human would produce contact current. See also: open-circuit voltage.
~~Voltage between a biological medium and an electrode or current source in the absence of direct contact with the body.~~

~~3.1.16 controlled environment: An area where the occupancy and activity of those within is subject to control and accountability as established by an RF safety program for the purpose of protection from RF exposure hazards. See also: general public.~~

~~NOTE—Implementation of an effective RF safety program such as IEEE Std C95.7-2005 is to ensure that persons are not exposed in excess of the “Controlled Environment” MPEs.~~

continuous exposure: For purposes of this standard, exposure for durations exceeding the corresponding averaging time.

NOTE 1—In this context, exposure for less than the averaging time is considered a short-term exposure.

NOTE 2—For cellular studies in the laboratory, continuous exposure refers to exposures for most of the cell cycle of a proliferating cell system (or longer), while for nonproliferating cells *in vitro* or in tissues, “continuous exposure” is arbitrary. For cellular studies, “short term” refers to, at most, exposure over a small portion of the cell cycle time. With respect to nonproliferating cells *in vitro* or in tissues, the definition is arbitrary.

controlled environment: Deprecated. See: exposure environment; restricted environment.

core temperature: The temperature of the internal structures of the body.

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

NOTE—Corona by-products can include RF fields, audible noise, and trace amounts of ozone.

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

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

current density: The ratio of the flowing current to the cross-sectional area perpendicular to the direction of the current.

NOTE—The SI unit of current density is ampere per square meter (A/m^2).

depolarization (cellular): The reduction of the potential across a cellular membrane relative to its resting value.

direct electrostimulation: Deprecated. See: **induced electrostimulation.**

dosimetric reference limit (DRL): The exposure limit based on dosimetric thresholds for established adverse health effects expressed as *in situ* electric field strength (0 Hz to 5 MHz), specific absorption rate (100 kHz to 6 GHz), or epithelial power density (6 GHz to 300 GHz) and which provides an adequate margin of safety.

NOTE 1—DRLs are defined in conjunction with specified spatial and temporal averaging requirements.

NOTE 2—DRLs are equivalent to the quantity previously referred to as basic restrictions.

dosimetry: The discipline that quantifies the relationship between external exposure quantities and internal dose and dose rate quantities. See also: **specific absorption; specific absorption rate.**

NOTE—External exposure quantities include electric field, magnetic field, and electromagnetic field (incident power density); internal quantities include *in situ* electric field, dose, dose rate, specific absorption (SA), specific absorption rate (SAR), and epithelial power density, respectively.

duty cycle: See: **duty factor.**

duty factor: The ratio of pulse duration to the pulse period of a periodic pulse train.

NOTE—A duty factor of 1.0 corresponds to continuous-wave (CW) operation.

effect threshold: The threshold for a biological effect but not necessarily for an adverse effect.

electric field strength (E): Force exerted by an electric field on an electric point charge, divided by the electric charge.

NOTE—The SI unit for electric field strength is newton per coulomb or volt per meter ($N/C = V/m$).

electric field: A fundamental component of electromagnetic waves, which exists when there is a potential difference between two points in space.

electromagnetic field (EMF): The energy field radiating from a source and containing both electric and magnetic field components.

electromagnetic interference (EMI): Any electromagnetic disturbance, whether intentional or not, which interrupts, obstructs, or otherwise degrades or limits the effective performance or safe operation of an electronic or electrical device or system.

electrostimulation (ES): Induction of a propagating action potential in excitable tissue by an applied electrical stimulus; electrical polarization of presynaptic processes leading to a change in postsynaptic cell activity.

NOTE—Electrostimulation involves excitation of nerve and/or muscle tissue.

environmental field: An electric, magnetic, or electromagnetic field external to the body and measured in the absence of the body (in order not to perturb the field).

epithelial energy density: The energy flow through the epithelium per unit area directly under the body surface (i.e., in stratum corneum of the skin or corneal epithelium of eyes).

NOTE—The SI unit for epithelial energy density is joule per square meter (J/m^2).

epithelial power density: The power flow through the epithelium per unit area directly under the body surface (i.e., in stratum corneum of the skin or corneal epithelium of eyes).

NOTE 1—The SI unit for epithelial power density is watt per square meter (W/m^2).

NOTE 2—In this standard, the epithelial power density just inside the body surface is employed to define local dosimetric reference limits at frequencies greater than 6 GHz.

3.1.18 derived limits: ~~See: maximum permissible exposure.~~

~~3.1.19 environmental limit:~~ A limit on the electric and magnetic fields permitted in the general environment, whether or not people are present.

~~3.1.20 equivalent plane-wave power density (plane-wave equivalent power density) (S):~~ 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. Specifically, the normalized value of the square of the electric or the magnetic field strength at a point in the near field of a radiating source. The SI unit of equivalent plane-wave power density is the watt per square meter (W/m^2) and is computed as follows:

$$S = \frac{|E|^2}{\eta} = \eta |H|^2$$

(Deleted)

where

~~E and H are the root mean square (rms) values of the electric and magnetic field strengths, respectively,~~

~~and~~

~~η is the wave impedance (≈ 377 ohms in free space).~~

~~Synonym: equivalent plane-wave power flux density.~~

established adverse health effect: An effect detrimental to the health of an individual due to exposure to an electric, magnetic, or electromagnetic field, or to induced or contact currents, with the following characteristics:

- a) It is supported by the weight of the evidence of that effect in studies published in the scientific literature.
- b) The effect has been demonstrated by independent laboratories.

- c) ~~A biological effect characterized by a harmful change in health that is supported by consistent findings of that effect in studies published in the peer-reviewed scientific literature, with evidence of the effect being demonstrated by independent laboratories, and where~~ There is consensus in the scientific community that the effect occurs for the specified exposure conditions. ~~The development of this standard is based on the following established adverse health effects: 1) aversive or painful electrostimulation due to excessive RF internal electric fields, 2) RF shocks or burns due to contact with excessively high RF voltages, 3) heating pain or tissue burns due to excessive localized RF exposure, and 4) behavioral disruption, heat exhaustion or heat stroke due to excessive whole-body RF exposures. See: **adverse health effect**.~~

See also: **adverse health effect**.

~~**3.1.22 established effect:** An effect is considered *established* when consistent findings of that effect have been published in the peer-reviewed scientific literature, with evidence of the effect being demonstrated by independent laboratories, and where there is consensus in the scientific community that the effect occurs for the specified exposure conditions.~~

established mechanism: For purposes of this standard, a mechanism with the following characteristics: ~~characteristics: (1)~~

- a) It can be used to explain or describe ~~predict~~ a biological effect in cells, animals, or humans. ~~;~~ ~~(2)~~
- b) An explicit model is ~~can be~~ proposed using equations or parametric relationships. ~~;~~ ~~(3)~~
- c) It has been verified in humans, or in animal data, thus, supporting confidence that the mechanism can be ~~confidently~~ extrapolated to humans. ~~;~~ ~~(4)~~
- d) It is supported by scientific ~~strong~~ evidence. ~~;~~ ~~and (5)~~
- e) It is widely accepted among experts in the scientific community.

exposure: The state of being in the presence of electric, magnetic, or electromagnetic fields, or in contact with a current or voltage source.

~~For purposes of this standard, exposure of a person to electric, magnetic, or electromagnetic fields or to induced and contact currents other than those originating from physiological processes in the body and other natural phenomena.~~

exposure environment: A defined area that is characterized by the maximum potential exposure that could occur within it.

a) **restricted environment:** An environment in which exposure can result in exceeding the unrestricted environment (lower tier) dosimetric reference limit (DRL). See also: **restricted tier**.

NOTE 1—Implementation of an effective safety program (see IEEE Std C95.7 for the RF range) is to help ensure that persons are not exposed above the DRL or ERL for the restricted environment.

NOTE 2—In some documents, exposure in restricted environments is referred to as “upper tier” or “controlled environment” or “occupational exposure.”

NOTE 3—Members of the general public are not permitted in restricted environments unless they become subject to the applicable safety program, at which time they are no longer considered members of the “general public.”

b) **unrestricted environment:** An environment in which exposure does not result in exceeding the dosimetric reference limit (DRL) that marks the safety program initiation level, and which serves as an exposure limit for the general public. See also: **unrestricted tier; general public**.

NOTE 1—The exposures can occur in living quarters or workplaces where there are no expectations that the DRL or ERL for unrestricted environments would be exceeded and where the induced currents or contact currents do not exceed the limits for unrestricted environments.

NOTE 2—In some documents, the unrestricted environment is referred to as a “lower tier” or an “uncontrolled environment” or a “general public exposure.”

exposure reference level (ERL): The maximum exposure level relative to ambient electric and/or magnetic field strength or power density, induced and/or contact current, or contact voltage.

NOTE 1—ERLs provide an adequate margin of safety against established adverse health effects.

NOTE 2—The ERL is expressed as the metric appropriate to the frequency and temporal characteristics of the exposure under consideration.

NOTE 3—The ERL is measured, estimated, or derived from the DRL (*in situ* electric field, SAR, or epithelial power density).

NOTE 4—The ERL may be exceeded if it can be demonstrated that the corresponding DRL is not exceeded. NOTE 5—The ERLs and DRLs for contact current are the same.

NOTE 6—In some documents, ERLs are called reference levels, derived limits, permissible exposure limits, maximum permissible exposure values, action levels, or investigation levels.

extra systole: A heartbeat occurring before its normal time in the rhythm of the heart and followed by a compensatory pause.

extremities: Deprecated. See: **limbs**. ~~For purposes of this standard, the parts of the arms and legs distal from the elbows and knees, respectively.~~

far-field (region): ~~The~~ That ~~region of the field of an antenna~~ where the angular field distribution is essentially independent of ~~the~~ distance from the source 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.~~

NOTE—In the far-field region, the field has a predominantly plane-wave character (i.e., locally very uniform distributions of electric field strength and magnetic field strength in planes transverse to the direction of propagation). For large antennas especially, the far-field region is also referred to as the “Fraunhofer region.”

fluence: A measure of the energy per unit area of exposure contained in a pulse of electromagnetic radiation, that for the purposes of this standard is quantified by the product of the intensity of the pulse (W/m^2) times the pulse duration (s). See also: **incident energy density**.

NOTE—The SI unit for fluence is joule per square meter (J/m^2).

general public: All members of the human population who have no knowledge or control of their exposure and are, consequently, not permitted in a restricted environment. The unrestricted tier exposure limit applies to the general public. See also: **exposure environment (unrestricted)**.

~~Individuals of all ages and varying health status, some of whom may be subject to requirements of the controlled environment. See: **controlled environment**.~~

NOTE—The general public includes, but is not limited to, children, pregnant women, individuals with impaired thermoregulatory systems, ~~individuals equipped with electronic medical devices,~~ and persons using medications that can ~~may~~ result in poor thermoregulatory system performance.

~~NOTE 2—Unless specifically provided as part of an RF safety program, individual members of the public may not be aware of their exposure.~~

grasping contact: An electrical connection with a large energized conductor made by firmly holding the conductor in the hand.

NOTE—For purposes of computation ~~In this standard,~~ a contact area of 15 cm^2 is assumed. ~~for such contact.~~

grip tetanus: A condition where an electrical stimulus causes the hand to “freeze” its grip on an object. The threshold of grip tetanus is also called the let-go current. See also: **let-go current**.

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

hazard: An intrinsic property or condition that has the potential to cause an adverse health effect.

hazard threshold (HT): The level point above which an ~~some parameter related to~~ exposure, expressed ~~(e.g., SAR,~~ in terms of the appropriate metric, can result in a hazard. ~~the electric field strength) is associated with the existence of some hazardous effect.~~

hertz (Hz): The SI unit of frequency, equal to one cycle per second.

NOTE—Common multiples are kilohertz (kHz; 1000 Hz), megahertz (MHz; 1 000 000 Hz), and gigahertz (GHz; 1 000 000 000 Hz).

incident energy density: For purposes of this standard, the quantity of energy per unit area that impinges on the body surface. See also: fluence.

NOTE—The SI unit for incident energy density is joule per square meter (J/m²).

incident power density: For purposes of this standard, the quantity of power per unit area that impinges on the body surface. See also: power density.

NOTE 1—The SI unit for incident power density is watt per square meter (W/m²).

NOTE 2—In this standard, the incident power density just outside the body surface is employed to define local exposure reference levels at frequencies greater than 6 GHz.

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

induced current: Electric current flowing in the body of a person in a freestanding condition (no skin contact with conductive objects) due to an electromagnetic field.

NOTE—For compliance with standards, this is normally measured as the current through the feet or ankles of the person to ground with the use of current transformers having a sufficient aperture size to fit around the ankle.

in silico: Performed on computer or via computer simulation.

in situ: For purposes of this standard, *in situ* means within a biological tissue in its normal anatomical position.

in vitro: Refers to studies and/or effects that occur in an artificial environment outside a living organism.

in vivo: Refers to studies and/or effects that occur within the body of living organisms.

induced 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.

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

joule (J): A unit of energy.

NOTE—One (1) joule = 1 watt second.

let-go current: The current level above which involuntary muscular contraction prevents release of a grip on an energized conductor. *See also:* **grip tetanus.**

NOTE 1—“Let-go current” is the preferred term but is often used interchangeably with “can’t let go current” or “lock-on current.”

NOTE 2—“Let-go” has occasionally been used for the threshold for withdrawal from an aversive stimulus.

limb: An entire leg or arm.

local exposure: An exposure condition in which a limited portion of the body is subject to most of the incident energy and is usually the result of: 1) the source being located very close to the body, or 2) a highly concentrated region of energy associated with contact with an energized conductor exposed to environmental fields.

lock-on current: See: **let-go current**.

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

~~**3.1.33 localized exposure:** For frequencies exceeding 100 kHz, an exposure of a portion of the body wherein the incident plane-wave equivalent power density, or the squares of the field strength exceed 20 times the spatially averaged value over the projected (cross-sectional) area of the body. See: **RF hot spot**.~~

long-term exposure: Exposure for a duration much longer than the corresponding averaging time. See also: **chronic exposure**.

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

lower tier: See: **unrestricted tier**. See also: **exposure environment (unrestricted)**. ~~A set of limits that provide an additional margin of safety, i.e., a margin of safety greater than that for the upper tier. See: **action level**.~~

lowest observed adverse effect level (LOAEL): The lowest exposure level at which there is a biologically significant increase in occurrence or severity of an adverse effect in the exposed study population compared with its appropriate control group.

lowest observed effect level (LOEL): Lowest concentration or amount of a substance or physical agent, found by experiment or observation, that causes any alteration in morphology, behavior, functional capacity, growth, development, or lifespan of target organisms distinguishable from normal (control-sham exposed) organisms of the same species and strain.

~~NOTE—The lower tier, which is recommended as an action level above which an RF safety program should be implemented, recognizes public concerns, uncertainties in exposure assessment, and supports the process of harmonization with other standards.~~

low-level effects: Biological effects ascribed to exposure to low-level electric, magnetic, or electromagnetic fields, that is i.e., at or below the corresponding dosimetric reference limits, taking exposure duration into account, ~~basic restrictions~~ in the frequency range covered in this standard (0 Hz 3-kHz to 300 GHz).

low-level fields: Electromagnetic fields in the frequency range 0 Hz 3-kHz to 300 GHz that produce induced (*in situ*) electric fields, specific absorption rate (SAR), or epithelial power density at or below the corresponding dosimetric reference limits ~~basic restrictions~~.

magnetic field: A fundamental component of electromagnetic waves produced by a moving electric charge.

magnetic field strength (H): The magnitude of the magnetic field vector.

NOTE—The SI unit of magnetic field strength is ampere per meter (A/m).

magnetic flux density (B): A vector quantity that determines the force on a moving charge or charges (electric current).

NOTE 1—The SI unit of magnetic flux density is tesla (T).

NOTE 2—In air and simple (nonmagnetizable) media, B is related to the magnetic field strength H by $B = \mu \times H$, where μ is the permeability of the medium.

NOTE 3—One gauss (deprecated unit) equals 10^{-4} T.

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

margin of safety: The ratio of the lowest observed adverse effect ~~minimum hazard threshold (HT)~~ level to the maximum exposure level, with accounting for all uncertainties in HT and the exposure level (LOAEL) to the dosimetric reference limit, after adjusting for possible measurement uncertainty, in a specific exposure situation.

NOTE 1—This is equivalent to the minimum possible safety factor when uncertainties are accounted for, while the nominal safety factor is ~~interpreted as that~~ derived from the LOAEL ~~median measures of HT~~ and dosimetric reference limit ~~basic restriction~~ or exposure reference level MPE. The margin of safety can approach equality with the safety factor if the uncertainties are small or if there is a very large separation between the LOAEL and the established adverse health effects level ~~HT and the MPE. The margin of safety is a value judgment based on informed opinion.~~

NOTE 2—The safety factor incorporates uncertainties and environment safety factor values and is, therefore, somewhat arbitrary and is partially based on the value judgments from all stakeholders.

maximum permissible exposure (MPE) value: Deprecated. See: exposure reference level.

mean: The arithmetic average of a series of numerical values.

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

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

~~3.1.39 maximum permissible exposure (MPE): The highest rms or peak electric or magnetic field strengths, their squares, or the plane-wave equivalent power densities associated with these fields, or the induced and contact currents to which a person may be exposed without incurring an established adverse health effect and with an acceptable margin of safety. The MPEs are derived or estimated from the basic restrictions (induced electric field, SAR, or power density). If an exposure is proven to be below the basic restrictions, the MPE can be exceeded. MPEs are sometimes called reference levels, derived limits, or investigation levels.~~