

IEEE Standard for Military Workplaces—Force Health Protection Regarding Personnel Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz

IEEE Technical Committee 95

Sponsored by the
IEEE International Committee on Electromagnetic Safety (SCC39)

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IEEE-SA Standards Board

Abstract: Recommendations to protect personnel in military environments against established adverse health effects associated with exposure to electric, magnetic, and electromagnetic fields, induced and contact current, and contact and arcing voltages over the frequency range of 0 Hz to 300 GHz are provided in this standard. IEEE Std C95.1-2345™ was developed to replace North Atlantic Treaty Organization (NATO) Standardization Agreement (STANAG) 2345 (Edition 3), Evaluation and Control of Personnel Exposure to Radio Frequency Fields—3 kHz to 300 GHz, (13 February 2003).

Keywords: Dosimetric reference limit (DRL), electric fields, electrical excitation, electromagnetic energy, electromagnetic fields, electrostimulation, exposure limits, exposure reference level (ERL), IEEE C95.1-2345™, induced and contact currents, lowest-observed-adverse-effects-level (LOAEL), lowest-observed-effects-level (LOEL), magnetic fields, personnel protection program initiation level, radio frequency (RF), restricted environment, restricted expert only (REO) zone, RF exposure, RF risk management, specific absorption rate (SAR), unrestricted environment

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Introduction

This introduction is not part of 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.

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, Incorporated (IEEE). 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 (SCC 28) under the sponsorship of the IEEE Standards Board. In 2001, the IEEE Standards Association Standards Board approved the name “International Committee on Electromagnetic Safety (ICES)” for SCC 28 to better reflect the scope of the committee and its international membership. In accordance with policies of 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, SCC 28 and SCC 34 became Technical Committee 95 and Technical Committee 34, respectively, under a new IEEE Standards Coordinating Committee, SCC 39, 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 five TC95 subcommittees, each of whose area of responsibility is described as follows in correspondence with its designated subcommittee number:

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

This standard was prepared by Subcommittee 3 and Subcommittee 4 of TC95 under a Specific Agreement between NATO Standardization Agency (NSA) and IEEE in accordance with a Technical Cooperation Agreement (TCA) between NSA and IEEE. TC95 has issued four standards, four recommended practices, and one guide. Present versions are as follows:

- 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.
- 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.

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.

- IEEE Std C95.2™-1999 (R2005), IEEE Standard for Radio-Frequency Energy and Current-Flow Symbols.
- IEEE Std C95.3™-2002 (R2008), Recommended Practice for Measurements and Computations of Electric, Magnetic and Electromagnetic Fields With Respect to Human Exposure to Such Fields, 100 kHz-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 C95.6™-2002 (R2007), IEEE Standard for Safety Levels With Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz.
- IEEE Std C95.7™-2005, IEEE Recommended Practice for Radio Frequency Safety Programs, 3 kHz to 300 GHz.
- IEEE Std 1460™-1996, (R2008), IEEE Guide for the Measurement of Quasi-Static Magnetic and Electric Fields.

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1. Overview

1.1 Scope

This standard provides recommendations to protect personnel in military environments against established adverse health effects associated with exposure to electric, magnetic, and electromagnetic fields, induced and contact current, and contact and arcing voltages over the frequency range of 0 Hz to 300 GHz. The recommendations, expressed as dosimetric reference limits (DRLs) and exposure reference levels (ERLs), incorporate safety factors that address uncertainties such as uncertainties in the experimental data, measurement uncertainties, and differences in threshold variability between individuals, so as to establish an appropriate margin of safety. The DRLs are expressed in terms of *in situ* electric field strength, specific absorption rate (SAR), and incident power density. The ERLs are expressed in terms of environmental exposure fields and power densities. In the case of contact current, however, only ERLs are provided. The DRLs and ERLs are intended to protect against established adverse human health effects associated with electrostimulation of tissue and partial and whole-body heating, but may not protect against electromagnetic interference (EMI) with implanted medical devices. This standard does not apply to

exposure of informed volunteers in medical or scientific research studies subject to approval by institutional review boards for the use of human subjects, nor does it include exposure assessment techniques, risk management/safety program procedures, warning sign design, procedures for medical treatment of suspected overexposures, nor assessment of hazards associated with exposure of ordnance, fuel, or electro-explosive devices.¹

1.2 Purpose

The purpose of this standard is to provide science-based exposure limits for incorporation into a safety and occupational health (SOH) risk management program to protect personnel in a military workplace against established adverse health effects associated with exposure to electric, magnetic and electromagnetic fields, induced and contact currents, and contact (and arcing) voltages over the frequency range of 0 Hz to 300 GHz.

1.3 Introduction

This voluntary consensus standard was prepared under a Specific Agreement [B24] between NATO Standardization Agency (NSA) and IEEE in accordance with a Technical Cooperation Agreement (TCA) [B25] between NSA and IEEE to develop a new civil standard to replace the NATO standard adopted under STANAG 2345.² Adoption of this standard requires that the recommended exposure limits shall be implemented for compliance.³

Exposure limits are presented to provide risk managed SOH operational environments and protect military personnel and non-military persons (e.g., general public in military workplaces) against established adverse health effects associated with exposure to electric, magnetic, and electromagnetic fields and contact currents (and arcing voltages) in the frequency range of 0 Hz to 300 GHz.⁴ From 3 MHz to 20 MHz, there is limited scientific information on contact currents and arcing voltages. Because of a lack of experimental data, the ERLs for induced and contact currents above 20 MHz expressed in this standard are based on extrapolation and conservative judgments.

This standard is based on IEEE Std C95.1™-2005 and IEEE Std C95.6™-2002, which at the time of drafting this standard were being revised and merged.⁵ Detailed explanatory or informative description is not included in this standard; the reader is referred to IEEE Std C95.1™-2005 and IEEE Std C95.6™-2002. At 300 GHz, the ERLs in this standard are consistent with those found in standards that cover infra-red wavelengths (frequencies above 300 GHz), e.g., ANSI Z136.1-2007 [B3] and IEC 60825-1 [B13].

Safety factors reduce the allowed exposure levels, thereby providing a margin of safety below the established adverse health effects level. In restricted zones, safety factors may be relaxed and specialized higher exposure values set to meet personnel protection requirements for the military environments and systems with electromagnetic characteristics unique to the military, recognizing the high rigor of military risk management programs. DRLs and ERLs to protect against established adverse health effects to humans from exposures to electric, magnetic, and electromagnetic fields and contact currents and recommendations to protect against arcing voltages have been defined on the basis of a comprehensive review of the scientific literature (see IEEE Std C95.1™-2005 and IEEE Std C95.6™-2002). Based on the results of this review, established mechanisms of interaction were found to be stimulation of excitable nervous tissue by

¹ This information can be found in other C95 standards such as IEEE Std C95.2™ [B18], IEEE Std C95.3™ [B19], IEEE Std C95.3.1™ [B20], IEEE Std C95.4™ [B21] and IEEE Std C95.7™ [B22].

² The numbers in brackets correspond to those of the bibliography in Annex D.

³ A standardization agreement (STANAG) is an official record of agreement among a majority of the NATO nations to adopt similar material or procedures. (See the procedures for developing, preparing, producing, and updating STANAGs [B1].)

⁴ The frequencies and wavelengths covered by this standard are in the “non-ionizing” region of the electromagnetic spectrum.

⁵ Information on references can be found in Clause 2.

electric fields induced within the body (frequencies between 0 Hz and approximately 5 MHz), and tissue heating (frequencies above about 100 kHz). In the transition region of 100 kHz to 5 MHz, the more restrictive of the electrostimulation and tissue heating ERLs apply: generally 1) ERLs associated with heating are more restrictive for long-term (i.e., greater than the averaging time) exposures to continuous wave (CW) fields, and 2) ERLs based on electrostimulation will be more restrictive for short-term exposure (e.g., short isolated pulses of low duty factor).

1.3.1 Dosimetric reference limits (DRLs) and derived exposure reference levels (ERLs)

The DRLs and ERLs incorporate safety factors that account for biological variability and experimental measurement uncertainties, extrapolation from *in vitro*, animal and human studies, and for the variability of response thresholds within the study population, as well as environment reduction factors, thus providing margins of safety for all (see 1.3.4).⁶ The DRLs, which are limits on *in situ* electric field strength, specific absorption rate (SAR), and incident power density, serve to protect personnel against exposures leading to adverse health effects caused by stimulation of excitable tissue and partial and whole-body heating. ERLs, which provide limits on environmental exposure fields, induced and contact currents and voltages, provide a convenient method to determine compliance with the DRLs by measurement or computation. Because the ERLs are conservatively derived from the DRLs, it is possible to exceed an ERL while still complying with the DRL except for frequencies above 3 GHz where the DRLs and ERLs, both expressed in terms of incident power density, are identical.⁷

1.3.2 Protected populations

Protection is to be afforded to personnel in a structure comprising zones of increasing allowable exposure with concomitant increased restrictions on access and increased safety practices. The DRLs and ERLs are intended to apply to all people, as categorized by their training and expertise and by the level of rigor of the protection program in use. Note that exposures to electric, magnetic, and electromagnetic fields associated with procedures for medical diagnosis or treatment are not covered by this standard. This exception is provided under the expectation that the medical staff is appropriately trained in minimizing risk to themselves and minimizing the risk of adverse health effects to patients concomitant with the provision of a recognized benefit from the exposure. Experts highly trained on a specific system or equipment may be allowed (by command or designated delegate) access to a special zone in the restricted environment, the restricted expert only (REO) zone, Zone 2, to carry out necessary activities under strict and explicit guidelines. This exception is provided with the same expectation as that provided to medical staff that such personnel will have been sufficiently trained on minimizing their risk. This standard does not apply to exposure of informed volunteers in medical or scientific research studies, 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 may exhibit susceptibility to EMI.

1.3.3 Military environmental exposure zones

The military personnel workplace electric, magnetic, and electromagnetic field (EMF) exposure environments covered in this standard are divided into two exposure environments (restricted and unrestricted) and three zones (Zone 0, Zone 1, and Zone 2). Zone 0 applies to unrestricted environments; Zone 1 and Zone 2 apply to restricted environments. Zone 1 is restricted to informed personnel with appropriate training; Zone 2 requires additional specialized training, monitoring, and is allowed only under unique circumstances (see Figure A.1).

⁶ The safety factors also support the process of harmonization with recommendations and guidelines of other national and international groups, e.g., NCRP [B30] and ICNIRP [B10], [B11].

⁷ While there may be atypical cases where compliance with the ERLs may not ensure compliance with the DRLs, compliance with the ERLs means compliance with this standard.

1.3.3.1 Unrestricted environments

1.3.3.1.1 Zone 0

Although this is a military workplace standard, Zone 0 is included, which allows access by all persons. This takes into consideration areas on military bases, maritime vessels, and installation environments that are open to all personnel, such as recreational areas and eating and sleeping quarters.

1.3.3.1.2 Implementation of a personnel protection program

The ERLs delineating the boundary between Zone 0 and Zone 1 serve as a trigger, or an initiation level, for implementation of a personnel protection program. A personnel protection program, such as described in IEEE Std C95.7™-2005, shall be implemented whenever the ERLs for Zone 0 could be exceeded, unless it can be shown that the DRLs are not exceeded. Implementation of a risk management personnel protection program, including education and various mitigating measures, can be taken to reduce the likelihood of exposure to levels that cause adverse health effects. This also reduces uncertainties associated with detection, measurement, engineering, and administrative controls, and allows relaxation of the exposure values for appropriately trained/informed personnel.

1.3.3.2 Restricted environments

1.3.3.2.1 Zone 1

Only informed personnel instructed on the potential SOH risks of EMF overexposure and the personnel protection program requirements are allowed entry to restricted environment areas where exposures may exceed the Zone 0 ERLs but not the Zone 1 ERLs.

1.3.3.2.2 Zone 2

Zone 2 (restricted expert only) is a mission-essential working zone wherein limited access is under command discretion. Access to Zone 2 is limited to personnel who have work-related need for access and are appropriately trained, equipped, and monitored (with limits and additional controls and restrictions in place). Zone 2 permits specialized EMF technical experts and scientific research and development experts highly trained on specific systems or equipment to carry out necessary activities under strict and explicit guidelines. Limits for Zone 2 will be dependent on electromagnetic environmental effects (E3) characteristics such as frequency and power and shall not exceed the established adverse health effects level. Zone 2 ERLs are not explicitly defined in this standard, except for contact currents, but should not exceed five (5) times the Zone 1 ERL at frequencies where thermal mechanisms predominate.⁸ Zone 2 ERLs shall be developed for each specific environment and system that can exceed Zone 1 ERLs and that may require access. Zone 2 ERLs shall be considered alternative exposure policy and shall individually, by system, be reviewed and approved by a review board consisting of medical, research, standardization, and operational experts in EMF.

Zone 2 provides a protective zone below the established adverse health effect level, but with reduced safety factor values compared with Zone 1, in recognition of the rigorous military risk-management programs and the specialized expertise required for entry. Additionally, personnel would not be expected to include members of the population with medical concerns such as challenged thermoregulatory systems.

⁸ At frequencies where electrostimulation is the dominant mechanism, exposures above the upper boundaries of Zone 1 should not be tolerated.

1.3.3.2.3 Zone 3

Zone 3 (restricted off-limits) ERLs represents a no-access buffer zone, which exceeds the Zone 2 ERLs but is lower than the adverse health effect level.

NOTE—Zone 3 requires Warning and Danger signs and possibly barriers to prevent access. This restriction on access is placed to prevent personnel from exposure to the established adverse health effect level under normal operational procedures and does not apply to emergency situations.

1.3.4 Safety factor and margin of safety

The term “safety factor” is commonly defined as the ratio of an adverse health effect exposure level to the corresponding specified exposure level. The margin of safety may be less than the safety factor because of finite uncertainties (e.g., confidence interval) in the measurement of exposure levels in the data from which adverse effect threshold values are determined and measurement uncertainty in determining any exposure level. There may be some uncertainty in the adverse health effect level.

The derivation of safety factor (and margin of safety) is different for reactions due to electrostimulation versus thermal effects. The DRLs for protection against effects of electrostimulation are derived from statistical data regarding the variation of pain thresholds below the 1% probability level. In addition, for Zone 0, an additional safety factor reduces the DRL to assure that the probability of a painful reaction is much less than 1%. This additional factor is not applied for Zone 1. The safety factor (for protection against heating effects) for both whole-body and localized exposures of duration greater than the averaging time have been estimated to have values of 10 for Zone 1 and approximately 50 for Zone 0. One should be cautious in comparing safety factors in situations in which the DRLs are fields with situations in which DRLs are power-related quantities such as SAR.⁹

1.3.5 Risk management personnel protection program

Risk of overexposure and adverse health effects can be reduced by an effective risk-management program (cf. IEEE Std C95.7™-2005). A multi-layer risk-reduction safety program shall be implemented, which typically is developed with input from electrical engineers, risk assessment and risk characterization experts, bioenvironmental engineers, radiation-safety officers, health physicists, and medical doctors trained in clinical care of EMF overexposure. Moreover, prior to gaining access to Zone 1 or to Zone 2 (where the safety factor and margin of safety are reduced), personnel shall be instructed on health effects and risk-management procedures associated with EMF exposure.

The DRLs and ERLs in this standard apply only in areas where people have access. When there may be access to areas where the Zone 0 DRLs may be exceeded, access and exposures shall be limited through the implementation of a risk management personnel protection program, such as that described in IEEE Std C95.7™-2005 for RF fields, to help ensure that persons permitted entry are informed and trained and will not be exposed in excess of the Zone 1 or the Zone 2 ERLs.

Although DRLs and ERLs are defined to protect against established adverse health effects, access to restricted environments (Zone 1 and Zone 2) shall require education and various mitigating measures to reduce the likelihood of persons being exposed to levels associated with established adverse health effects. Exposures can be mitigated with control measures that are appropriate to the anticipated exposure situation. Examples of such measures include frequency appropriate protective gloves or shoes, awareness programs designed to alert personnel to the possibility of exposure leading to adverse SOH effects, administrative or engineering controls designed to reduce exposures, or specific work practices that lessen the duration or intensity of exposure and help ensure personnel are not exposed above the defined limits. Accessibility to Zone 0 is unrestricted and includes the general public and personnel uninformed of the potential for

⁹ Use of dB (decibels) is one way of avoiding any confusion.

exposure or the adverse health effects associated with overexposure. Examples of unrestricted environments are living quarters and public areas.

1.3.6 Physiological effects

1.3.6.1 Frequencies below 5 MHz

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 are different. Below 100 kHz, this standard protects against exposure to levels resulting in aversive or painful effects associated with electrostimulation, which has a characteristic response time that is much less than one second. Exposures are thus assessed in terms of instantaneous fields or currents. DRLs for electrostimulation include both a “probability factor,” F_p , and an “uncertainty factor,” F_u that are applied to a median adverse-reaction threshold. The value of F_p , which is 1/3, protects against adverse reactions for all but a small segment of the population (<1%). F_u , when applied, is also a factor of 1/3 (for uninformed personnel), providing an additional margin to further reduce the probability of response in any “outlier” personnel not covered by F_p . Thus, when both are applied, the total safety factor is equal to 9 (reciprocal of $F_p \times F_u$). For Zone 0, $F_u = 1/3$ is applied to all body tissues except for peripheral nerve tissues of the extremities. For Zone 1 and Zone 2, $F_u = 1/3$ is applied only for cardiac tissue to exclude cardiac excitation, which can lead to dangerous arrhythmias, and $F_u = 1$ is applied to other sites (brain tissue and neural tissue within the trunk) because:

- a) An adverse reaction at the Zone 1 DRL would be expected to occur in no more than 1% of the population and much less than 1% of the population for cardiac arrhythmias;
- b) Electrostimulation that might occur below the Zone 1 DRL has no lasting adverse health effect;
- c) A personnel protection program is required when exposure of personnel exceeds the Zone 0 ERL;
- d) Personnel allowed access to restricted environments shall be made aware of the potential for adverse reactions and mitigation measures.

1.3.6.2 Frequencies between 100 kHz and 3 GHz

Above 100 kHz, the effects associated with exposure to CW fields transitions from electrostimulation to tissue and whole-body heating and exposures are assessed with reference to an averaging time that depends on whether the exposure is induced or through direct contact. Furthermore, the averaging time varies with frequency and at some frequencies depends on the zone designation, i.e., Zone 0 (unrestricted environments); Zone 1 (personnel permitted in restricted environments); and Zone 2 (for specialized expert personnel).

The frequency 100 kHz nominally represents a “thermal crossover” “transition range” below which electrostimulation effects dominate, and above which tissue and whole-body heating dominate for continuous wave exposure. However, for pulsed waveforms, especially those of a low duty factor, the upper frequency at which electrostimulation effects have been demonstrated to have lower thresholds than electrical heating effects reaches 5 MHz [B33]. This standard contains criteria to help protect against adverse electrostimulation effects for pulsed waveforms with carrier frequencies above 100 kHz (see 4.1.2.4).

For short duration exposures (less than the averaging time) at frequencies above 100 kHz, the DRLs and ERLs associated with tissue heating are related to energy, i.e., specific absorption (SA) or energy density. It is possible, however, to continue to use the DRLs and ERLs expressed in power terms, specific absorption rate (SAR), or power density or equivalent fields, recognizing their time dependence. In this case, the effect to be protected against includes tissue damage that can result from excessive heating or potentially adverse behavioral effects secondary to heating. For exposure durations considerably greater than the averaging time, the ERLs are extrapolated from the exposure levels and SARs from laboratory studies of non-human

species, specifically exposure levels and SARs that resulted in a behavioral disruption response, which is considered to be the most sensitive reproducible response to RF exposure indicative of a potential adverse health effect (D'Andrea et al. [B7]). This process results in conservative DRLs and ERLs because of the superior thermoregulatory capability of humans compared to experimental animals.

The safety factors for both whole-body and localized exposures have been estimated to be approximately 10 and 50 or more in terms of power density for Zone 1 and Zone 0, respectively. The margin of safety for the DRLs and ERLs is generally greater for whole-body exposure in the resonance region than for partial-body exposures (see IEEE Std C95.1™-2005, Annex C.2.2.1.1).

1.3.6.3 Frequencies above 3 GHz

For frequencies above 3 GHz, the effect being protected against is excessive heating—primarily surface heating. For localized exposure at frequencies where SAR is applicable, the averaging mass for peak spatial-average SAR for Zone 1 and Zone 2 is 10 g of tissue (increased from 1 g in earlier IEEE C95.1 standards, e.g., IEEE Std C95.1™-1991 [B16]). The averaging mass 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 in high water content tissues is about 1.6 cm, smaller than the depth of the averaging volume. Therefore, for frequencies above 3 GHz, power density now becomes both the DRL and the ERL. However, between 3 GHz and 6 GHz, either SAR or power density may be used to determine compliance. Because of the thinness of the layer heated, the thermal time constant is relatively short and heating may be rapid. However, heat is conducted into surrounding structures and the temperature rise is limited unless the exposure is prolonged.

Because the thermal time constant decreases with increasing frequency, the averaging time for the DRLs and ERLs also decreases with increasing frequency. For Zone 0, the averaging time decreases from 30 min at 5 GHz to 5 min at 30 GHz and to 2.8 min at 100 GHz, and finally to 10 s at 300 GHz. For Zone 1, the averaging time decreases from 6 min at 3 GHz to 0.5 min at 30 GHz, and to 10 s at 300 GHz. In both Zone 0 and Zone 1, the averaging time at 300 GHz is the same 10 s as found in the ANSI Z136.1 [B3] and IEC 60825-1 [B13] laser standards at 300 GHz. (See IEEE Std C95.1™-2005, Annex C.5.)

The human skin (the largest organ) vascular system in combination with the pulmonary-circulatory system serves as an excellent thermal barrier and regulator capable of protecting the body from sizeable variations in environmental temperature. Consequently the DRLs and ERLs (in terms of incident power density) are very conservative: For the entire 3 GHz to 300 GHz range, the safety factor for restricted areas is more than 10, and the safety factor for unrestricted environments ranges from more than 10 to 100. From 100 GHz to 300 GHz, the difference in the safety factors between Zone 0 and Zone 1 decreases with increasing frequency—at 300 GHz the DRL/ERLs (power density) for the zones are equal (100 W/m²) which is the same as that found in the ANSI Z136.1 [B3] and IEC 60825-1 [B13] laser standards at 300 GHz.

1.3.7 Absence of chronic adverse health effects at exposure levels below the DRLs and ERLs

Many reviews have evaluated the possibility of adverse health effects associated with chronic exposure (see IEEE Std C95.1™-2005). 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 scientific evidence does not demonstrate adverse health effects caused by chronic exposures below the ERLs.
- b) No biophysical mechanisms have been scientifically validated that would link chronic, low-level exposure (exposure below the DRLs) to adverse health effects.

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.¹⁰

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.

IEEE Std C95.3™-2002 (R2008), IEEE Recommended Practice for Measurements and Computations of Radio Frequency Electromagnetic Fields with Respect to Human Exposure to Such Fields, 100 kHz–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–100 kHz.

IEEE Std C95.6™-2002 (R2007), IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0–3 kHz.

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

3. Definitions, acronyms, abbreviations, and letter symbols

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.^{11,12}

3.1 Definitions

action level: Deprecated. *See:* **personnel protection program initiation level.**

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

adverse health effect: An effect detrimental to an individual's health and physical well-being due to overexposure (hazardous) to an electric, magnetic, or electromagnetic field or to induced or contact currents or voltages. *See also:* **established adverse health effect and overexposure (hazardous).**

NOTE 1—Adverse health effects do not include biological effects without a harmful health effect, nor changes in subjective feelings of well-being that are a result of anxiety about possible effects or imagined health effects nor impacts of infrastructure that are not physically related to the generation of electric, magnetic, or electromagnetic fields, or indirect effects caused by electromagnetic interference with electronic devices.

NOTE 2—Sensory perceptions *per se* are not considered adverse health effects. For example, a perception of warmth at millimeter and other wavelengths and the microwave auditory effect are not recognized as effects to be protected against by this standard.

¹⁰ IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>). No-cost to the user access to the applicable IEEE C95™ standards on the “IEEE Get Program” site: <http://standards.ieee.org/about/get/index.html>.

¹¹ *IEEE Standards Dictionary Online* subscription is available at:

http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.

¹² An effort has been made to use ISO rules and align terms and definitions in the NATO Terminology AP-06, AP-55, and STANAG 3968.

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

arc: A plasma bridge formed in a gap between two electrodes with sufficient potential difference, often accompanied by sparks.

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

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

where $P(t)$ is the instantaneous power. The SI unit of average power is watt (W).

NOTE—The time duration ($t_2 - t_1$) could be source related (e.g., the source repetition period, duty factor) or use related (e.g., the averaging time associated with the ERLs).

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. The SI unit of average power density is watt per square meter (W/m^2).

averaging distance: The distance over which the *in situ* electric field is averaged when determining compliance with dosimetric reference limits (DRLs) for electrostimulation.

averaging time (T_{avg}): The appropriate time period over which the exposure is averaged for purposes of determining compliance with the appropriate exposure reference level (ERL).

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

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.

biological effect: An 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 may occur without adverse health effects, or may even be beneficial; they may also cause harm in the short-term (e.g., a burn) without long-term consequences.

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