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Synopsis 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"

IEEE International Committee on Electromagnetic Safety Technical Committee 95*

ABSTRACT The newly released IEEE Std C95.1™-2019 defines exposure criteria and associated limits for the protection of persons against established adverse health effects from exposures to electric, magnetic, and electromagnetic fields, in the frequency range 0 Hz to 300 GHz. The exposure limits apply to persons permitted in restricted environments and to the general public in unrestricted environments. These limits are not intended to apply to the exposure of patients by or under the direction of physicians and care professionals, as well as to the exposure of informed volunteers in scientific research studies, or to the use of medical devices or implants. IEEE Std C95.1™-2019 can be obtained at no cost from the IEEE Get Program https://ieeexplore.ieee.org/document/8859679.

INDEX TERMS Non-ionizing radiation protection, radio frequency (RF), RF exposure, RF safety, dosimetric reference limit (DRL), exposure reference level (ERL), induced and contact currents, specific absorption rate (SAR), electric fields, magnetic fields, electromagnetic fields, (epithelial) power density, electrostimulation, general public, restricted environment, unrestricted environment.

BACKGROUND

In 1960, the American Standards Association approved the initiation of the Radiation Hazards Standards Project under the co-sponsorship of the US Department of the Navy and the Institute of Electrical and Electronics Engineers, Incorporated (IEEE); (called the "Institute of Radio Engineers (IRE)" at the time). The first C95.1 standard was published in 1966. In 2001, the IEEE Standards Association Standards Board approved the name "International Committee on Electromagnetic Safety (ICES)" to better reflect its international membership as well as the scope of its Technical Committees (TC): TC34, addressing compliance assessment methods, and TC95, addressing exposure safety. The scope of IEEE ICES TC95, which developed IEEE Std C95.1™-2019, is
"*Development of standards for the safe use of electromagnetic energy in the range of 0 Hz to 300 GHz relative to the potential hazards of exposure of man, volatile materials, and explosive devices to such energy. It is not intended to include infrared, visible, ultraviolet, or ionizing radiation. The committee will coordinate with other committees whose scopes are contiguous with ICES.*"

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

IEEE Std C95.1™-2019 [1] was prepared by SC 3 and SC 4. This synopsis is only a reference document and it is not designed to replace the standard. For a better understanding of the C95.1 standard, please download a free copy through the IEEE Get Program™. (https://ieeexplore.ieee.org/document/8859679). Non-IEEE members will have to

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set up a free account at the above link (top-right corner of the screen) to be able to download the standard. Information about the IEEE Get Program™is available at: https://standards.ieee.org/products-services/ieee-get-program.html.

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OVERVIEW

SCOPE

IEEE Std C95.1™-2019 specifies exposure criteria and limits to protect against established adverse health effects in humans associated with exposure to electric, magnetic, and electromagnetic fields in the frequency range of 0 Hz to 300 GHz. The limits, incorporating safety margins, are defined in terms of dosimetric reference limits (DRL) and exposure reference levels (ERL). DRLs are expressed in terms of *in situ* (i.e., internal to the body of the exposed person) electric field strength, specific absorption rate (SAR), and epithelial power density. ERLs, which are more easily determined through measurements or computational analysis, are limits on external electric and magnetic fields, incident power density, induced and contact currents, and contact voltages that are intended to ensure that the DRLs are not exceeded. DRLs and ERLs protect against adverse health effects associated with electrostimulation of tissue and local and whole-body heating and are intended to apply to common situations where persons are exposed to electric, magnetic, and electromagnetic fields in the stated frequency range. However, the exposure limits are not intended to address exposures of patients or human research subjects under professional supervision, for which potential risks and recognized benefits might apply. Furthermore, these limits might not prevent interference with medical and implantable electronic devices that may be susceptible to electromagnetic interference (EMI).

GENERAL INTRODUCTION

The 2019 update of the C95.1 standard incorporates revisions of IEEE Std C95.1™-2005 [2] and IEEE Std C95.6™-2002 [3], further merging them into a single document, thus covering a large swath of the non-ionizing radiation spectrum. Updated information is also included from IEEE Std C95.1-2345™-2014 [4] (addressing military workplaces and military personnel protection), which preceded this standard in combining and updating IEEE Std C95.1-2005 and IEEE Std C95.6-2002, introducing expanded, frequency-dependent exposure levels for contact currents, as well as new terminology such as "safety program initiation level," "unrestricted environments" 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. The literature review performed for IEEE Std C95.1-2005 constitutes a strong foundation for the 2019 edition (see C.2 to C.7 [1]). As discussed in A.1.7 [1], the ICES literature review working group (LRWG) found that many recent health agency and expert group reviews confirmed the protectiveness of the existing limits. The major changes in limits in the 2019 edition address DRLs and ERLs above 6 GHz as based on recent thermal modeling studies. Detailed reviews of scientific studies dealing with effects at frequencies above 6 GHz are included in C.8 [1]. Review of the extensive literature on electromagnetic field (EMF) biological effects, spanning seven decades, confirmed that electrostimulation remains the dominant effect at frequencies below 100 kHz (but possibly up to 5 MHz for pulsed fields) and that thermal effects dominate at frequencies above 5 MHz, while both require protective limits in the 0.1 MHz to 5 MHz range.

Examination of the literature on exposure to electromagnetic energy 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 [5], 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 IEEE Std C95.1™-2019 are protective against established adverse health effects.

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 IEEE Std C95.1™-2019.
b) No biophysical mechanisms have been scientifically validated that would link chronic exposures below levels specified in IEEE Std C95.1™-2019 to adverse health effects.

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. Nonetheless, ICES Subcommittees routinely evaluate new research and will, if appropriate, initiate revision of IEEE Std. C95.1-2019.

Various new definitions are introduced in IEEE Std C95.1™-2019. The terms unrestricted tier (lower tier) and restricted tier (upper tier) refer to ranges of permissible exposure levels, with each tier having an upper limit. The lower tier limit is designated as the "safety program initiation level" (rather than the "action level" as designated in IEEE Std C95.1™-2005) to emphasize that an EMF safety program is necessary if exposure levels exceed said limit and fall in the upper tier. It should be noted that the 2019 edition refers to the upper tier exposure limit as applicable to "persons permitted in restricted environments," to emphasize that individuals might occupy restricted environments, where the higher ERLs and DRLs are applicable, provided they follow applicable EMF 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 two-way radios, the lower tier DRL is applicable to devices available to the general public, while the higher tier DRL is applicable to professional use devices for which EMF exposure awareness information/training is provided.

PROTECTED POPULATION

IEEE Std C95.1™-2019 is intended to apply to all people, regardless of age, with sufficient safety factors incorporated to accommodate variations in health, body size, shape and environment. Patients undergoing procedures for medical diagnosis or treatment that require exposure to fields or currents in excess of the DRLs and ERLs are exempted. The medical-applications exemption is provided under the expectation that medical staff are appropriately trained in minimizing the risk concomitant with the provision of a recognized benefit from the exposure.

Application of IEEE Std C95.1-2019 is intended to offer protection to all persons in unrestricted exposure environments such as living quarters, public areas, and workplaces (unrestricted/lower tier), as well as to persons permitted in restricted environments (restricted/upper tier). For the latter, information or training on EMF exposure awareness must be provided under an acceptable EMF safety program, which may include compulsory exposure mitigation measures. 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 insulated 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™-2014 [6] for the RF frequency range).

SAFETY FACTORS

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 concerns electrostimulation, and above 100 kHz where the adverse effects being protected against are related to tissue heating. In the transition region of 100 kHz to 5 MHz, both electrostimulation and heating can occur. For frequencies above 6 GHz, 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 respective frequency ranges. Safety factors are implemented considering the effects for each frequency band.

RISK ASSESSMENT AND SAFETY PROGRAMS

An EMF safety program, such as described for the RF range 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 EMF exposure assessment. Any consequent EMF 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 peak spatial average SAR in tissues. Procedures to assure compliance with respect to the DRLs for either lower or upper exposure tiers, as appropriate, are developed within IEEE ICES TC34, frequently in conjunction with the International Electrotechnical Commission (IEC) Technical Committee 106.

EXPOSURE LIMITS

DRLs and ERLs for exposure to electric, magnetic, or electromagnetic fields are defined to protect against painful electrostimulation in the frequency range of 0 Hz to 5 MHz and to protect against adverse heating in the frequency range of 100 kHz to 300 GHz. In the transition region of 100 kHz to 5 MHz, protection against both electrostimulation and thermal effects is provided through both sets of limits. Below 100 kHz, only the electrostimulation limits apply, while above 5 MHz, only the thermal limits apply, and both sets of limits apply in the transition region (100 kHz to 5 MHz). Within the transition region, the limits based on electrostimulation are generally more limiting for low-duty-factor exposures, while the thermal-based limits are more limiting for continuous-wave fields. ERLs also are defined for contact currents, induced currents, and contact voltages for the frequency range of 0 Hz to 110 MHz.

Evaluation of compliance with this standard ideally includes a determination that the DRLs are not exceeded. This determination is difficult in most cases because it can only be carried out using sophisticated analytical or measurement techniques, which are often limited to laboratory-type settings. ERLs are derived from the DRLs to provide a readily assessed quantity via measurements or computations. The value of an ERL is determined such that when the measured exposure complies with the ERL, it is also in compliance with the DRL. An ERL, however, may be exceeded if it can be demonstrated that the corresponding DRL is not exceeded. Assessment of exposure to electric, magnetic, and electromagnetic fields may be accomplished by measurement and/or analysis, using appropriate instrumentation and measurement techniques or computational/analytical methods, as described in standards, such as IEEE Std C95.3 [7], IEEE Std C95.3.1 [8], and IEC 62232 [9].

In Clause 4 of IEEE Std C95.1™-2019, a total of 14 tables specify DRLs and/or ERLs for exposure to electric, magnetic, and electromagnetic fields for persons in unrestricted environments and persons in restricted environments. Tables 12 through Table 14 specifically are on the induced and contact current limits.

Table 1—DRLs for electrostimulation mechanisms (0 Hz to 5 MHz)

Table 2—Magnetic field ERLs for exposure of head and torso (0 Hz to 5 MHz)

Table 3—Magnetic field ERLs for the limbs (0 Hz to 5 MHz)

Table 4—Electric field ERLs (0 Hz to 100 kHz)—Whole-body exposure

Table 5—DRLs (100 kHz to 6 GHz)

Table 6—Local exposure DRLs (6 GHz to 300 GHz)

Table 7—ERLs for whole-body exposure of persons in unrestricted environments (100 kHz to 300 GHz)

Table 8—ERLs for whole-body exposure of persons permitted in restricted environments (100 kHz to 300 GHz)

Table 9—Local exposure ERLs (100 kHz to 6 GHz)—Persons in unrestricted environments

Table 10—Local exposure ERLs (100 kHz to 6 GHz)—Persons permitted in restricted environments

Table 11—Local exposure ERLs (6 GHz to 300 GHz)

Table 12—RMS induced and contact current ERLs for continuous sinusoidal waveforms based on ES effects—Frequencies between 0 Hz and 3 kHz

Table 13—RMS induced and contact current ERLs for continuous sinusoidal waveforms based on ES effects— Frequencies between 3 kHz and 5 MHz

Table 14—RMS induced and contact current ERLs for continuous sinusoidal waveforms (100 kHz to 110 MHz)

DIFFERENCES BETWEEN THIS STANDARD AND IEEE STD C95.6-2002 AND IEEE STD C95.1-2005

As summarized in B.1.2, these are differences from the previous standards:

a) IEEE Std C95.1-2005 [2] contains two tiers: an upper tier for "people in controlled environments" and a lower tier "action level" for implementing an RF safety program or MPE for the general public when an RF safety program is not available. In this standard, operational definitions are introduced. The terms "lower tier" ("unrestricted tier") and "upper tier" ("restricted tier") establish the maximum exposure limits for persons in unrestricted environments and for persons permitted in restricted environments, respectively.

b) A DRL replaces basic restriction, and an ERL replaces MPE, the terms used in the previous standard. The intent is to make the terms more explicit and understandable.

c) The safety program initiation level (previously "action level") is clarified as the ERL marking the transition point between the lower (unrestricted) tier and the upper (restricted) tier.

d) The upper frequency boundary for the whole-body-average specific absorption rate (WBA SAR) has been changed from 3 GHz to 6 GHz because of improved measurement capabilities and to harmonize with the anticipated revised ICNIRP guidelines [10].

e) The averaging time is 30 min for whole-body RF exposure and 6 min for local exposure. It is scientifically more appropriate to select the averaging time according to the absorbing mass, not according to the exposure tier.

f) The term "extremities" as used in IEEE Std C95.1-2005 is changed to "limbs" involving the whole arms and legs, instead of portions distal to the elbows and knees. This change is to harmonize with IEEE Std C95.6-2002 and the ICNIRP guidelines [11].

g) After the publication of more recent dosimetry findings, the local exposure ERL factor is now frequency dependent, instead of being a fixed factor of 20 times the whole-body ERL over a frequency band.

h) The upper tier whole-body exposure ERLs above 300 MHz are different from those in IEEE Std C95.1-2005 to maintain a consistent factor of 5 between tiers and to harmonize with ICNIRP guidelines.

i) The local exposure DRL and ERL for frequencies between 6 GHz and 300 GHz have been changed. The DRL is the epithelial power density inside the body surface, and ERL is the incident power density outside the body. The power density area for spatial averaging is defined as 4 cm^2. For smaller areas, relaxed limits are allowed.

j) Peak DRL and ERL limits for local exposures to pulsed RF fields are defined, and new fluence limits for single RF-modulated pulses above 30 GHz are introduced. The averaging area for single pulse fluence is 1 cm^2.

k) The previous induced current limit for both feet is considered an unrealistic condition and is removed. The induced current limits for a single foot are retained.

l) Root-mean-square (rms) induced and contact current limits for continuous sinusoidal waveforms (100 kHz to 110 MHz) are changed from those in Table 7 of IEEE Std C95.1-2005 to frequency-dependent values.

It should be noted that international harmonization of standards and guidelines is highly desirable. Much effort has been devoted to doing this for the IEEE Std C95.1-2019 standard and the current ICNIRP guidelines [10]. Yet, there remain differences. A description of the background and reasons for the differences is planned for a future paper.

INFORMATIVE ANNEXES A TO E

ANNEX A

Approach to revision of IEEE Std C95.1^{TM}-2005 and IEEE Std C95.6^{TM}-2002.

Subclause A.1 has subsections discussing: 1) Continuity of the IEEE standards revision process, 2) Open nature of the IEEE ICES standards development process, 3) Complete reassessment of the technical rationale, 4) Process clarifications, and appeals, 5) The literature surveillance effort. 6) Literature evaluation process, and 7) Identification of hazards and interaction mechanisms.

Subclause A.2 includes: 1) Basic concepts for developing the ERLs, 2) Publication of novel findings, supportive data, and general acceptance by the scientific community, 3) Assessing thresholds and dose-response relationships, and 4) Selection of safety factors and development of ERLs, and 4) Mechanisms of biophysical interaction for the three frequency bands (0-5 MHz, 100 kHz-300 GHz, 6 GHz - 300 GHz).

Subclause A.3 covers the adverse health effects of the three frequency bands.

ANNEX B

Rationale

Recent literature reviews by the ICES working groups and the literature review have not revealed reliable evidence that would change the scientific basis for the adverse effect levels. The adverse effect is electrostimulation at low frequency and heating at high frequency. The threshold for WBA SAR of 4 W/kg for established adverse effects remains the same as in the ANSI C95.1-1982 [5], and the IEEE Std C95.1-2005 [2]. Adoption was based on the decision that the threshold for disruption of ongoing behavior in laboratory animals including nonhuman primates can be extrapolated to potentially adverse effect in human beings. The peak spatial-average SAR (psSAR) values were changed in IEEE Std C95.1-2005 from 1.6 W/kg and 8 W/kg averaged over 1 g of tissue for exposure of the public and exposures in controlled environments to 2 W/kg and 10 W/kg averaged over 10 g of tissue, respectively. Modeling studies report the possibility of a 1 °C or greater rise in tissue temperature at 10 W/kg per 10 g. An increase of 1 °C had been suggested earlier as the upper temperature increase without detrimental health effects.

The rationale to set exposure limits for stimulatory effects at lower frequencies and temperature-related effects at higher frequencies has been explained thoroughly in this standard. Improved numerical and measurement methods in RF dosimetry have increased our understanding of the SAR-temperature relationship following RF energy deposition in human tissue, which is essential when assessing potential biological and health effects. In addition, to explain the rationale for adverse effect levels in the frequency range of 100 kHz to 300 GHz (see B.3), several special considerations have been reviewed and explained in detail in B.7 (for example, to cover extreme exposure situations of specific human subpopulations).

In summary, this standard incorporates a large margin of safety and a safety program is required to provide part of the margin of safety for those exposed above the lower tier level. This standard should also be considered especially conservative because the safety factors are applied against perception phenomena (electro-stimulation and behavioral disruption), which are far less serious effects than any permanent pathology or even reversible tissue damage that could occur at much higher exposure levels than those for perception phenomena.

In subsequent subclauses, rationales for the various frequency bands are explained in detail:

- B.2 Rationale for limits based on electrostimulation (0 Hz to 5 MHz)
- B.3 Rationale for limits based on heating (100 kHz to 300 GHz)
- B.4 DRL and ERL
- B.5 Adverse effect levels
- B.6 Averaging time
- B.7 Special considerations (Recognition of whole-body resonance; Nonuniform exposure fields; Near-field versus far-field exposures and SAR; Spatial considerations (peak versus whole-body average values); Tissue averaging mass considerations; Historical perspective on the evolution of the lower tier; Adverse environmental conditions and workloads; Presence of medical devices or metallic implants; Influences of medications; Pregnancy; Use of mobile telephones by children; and Macular degeneration).

ANNEX C

Identification of levels of exposure associated with adverse effects— summary of the literature

A review of the extensive literature on biological effects of electromagnetic fields reveals adverse health effects can occur as electrostimulation at low frequencies and thermal effects at high frequencies. This conclusion is consistent with those reached by other scientific expert groups and government agencies including many reviews or reports published up to the end of 2017, and also 2019 [12].

Further examination of the RF literature reveals no confirmed adverse health effects below current exposure limits that would occur even under unusually high heat loads from ambient thermal conditions and workload. The scientific consensus is that no accepted theoretical mechanisms exist that would suggest the existence of such effects. This consensus further supports the analysis presented in this annex that established harmful effects can occur due to excessive absorption of thermal energy from an RF field, leading to detrimentally elevated temperatures within tissue.

The accepted mechanism is RF energy absorbed by the biological system through interaction with polar molecules (dielectric relaxation) or interactions with ions (ohmic loss), which is rapidly dispersed to all modes of the system leading to an average energy rise or temperature elevation.

Since publication of ANSI C95.1-1982, significant advances have been made in our knowledge of the biological effects of exposure to RF energy. This increased knowledge strengthens the basis for and confidence in the statement that the ERLs and DRLs in this standard are broadly protective against established adverse health effects.

Since all expert reviews confirm the protectiveness of the current limits [12], and the fact that the only changes in limits in this standard are the dosimetric reference limits (DRL) and exposure reference levels (ERL) above 6 GHz, this annex includes reviews of scientific papers dealing with effects at frequencies higher than 6 GHz.

Subclauses C.2 to C.7 are essentially adapted from Annex B of IEEE Std C95.1-2005. Subclause C.8 contains review of literature above 6 GHz.

C.2 Identification of levels of RF exposure responsible for adverse effects—Summary of the literature (IEEE Std C95.1-2005, Annex B)
C.3 Role of mechanisms in determination of levels for adverse effects
C.4 Improvements in dosimetry
C.5 Established effects forming the basis of this standard
C.6 Noncancer-related studies
C.7 Cancer-related studies
C.8 Reviews of the literature (frequencies between 6 GHz and 300 GHz)

ANNEX D

Practical examples for compliance determinations—Applications

Often there are situations where determining compliance with this standard may be difficult and not always straightforward. This annex focuses on those portions of the standard that have traditionally been problematic for interpretation and implementation. Examples are shown on applying the peak power density limits, heat sealing application at 27 MHz, and evaluating polarization-dependent exposures. Subclause D.2 explains how to deal with multifrequency exposures (exposures to multiple sources). Subclause D.3 deals with RF field exposures consisting of intense pulsed power densities shall comply not only with the WBA ERL and local ERL but also with a limit on the fluence of the pulses (J/m^2 or kJ/m^2). Subclause D.4 has requirements for measurements of electric field and magnetic fields, induced currents, and contact voltage (frequencies above 100 kHz).

ANNEX E

Bibliography

Annex E contains 1550 references.

ACKNOWLEDGMENT

The Editorial Working Group that prepared this synopsis recognizes the many contributions of ICES TC 95 members during the development of IEEE Std C95.1-2019, especially Ron Petersen (deceased) who acted as secretary for many years.

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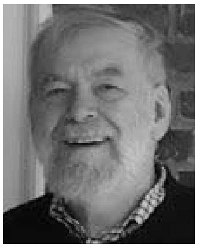
RALF BODEMANN received the Diploma degree in physics and the Ph.D. degree from the University of Hannover, in 1989 and 1993, respectively. From September 1993 to August 1995, he served as a Trainee with Deutsches Museum, Munich. From 1996 to 2001, he served as an Employers' Representative in the creation of German EMF regulation BGV B11. From 2004 to 2016, he represented the European employers in a consulting body of the European Commission. There, he monitored the revision of the European EMF workplace Directive 2013/35/EU and the related guide. From 2004 to March 2007, he was Vice-Chairman, and from April 2007 to February 2018, he was Chairman of the IEEE International Committee on Electromagnetic Safety (IEEE-ICES). In this period, he facilitated the progress of numerous IEEE standards, and he represented ICES at various external events mainly in Europe. Since October 1995, he has been a Senior Expert in radiation safety with Siemens AG, Munich. Since July 2000, he has been a member of IEEE SCC-28, which merged with IEEE-SCC34 to IEEE-SCC39 also known as IEEE-ICES. He participated in preparing the Technical Co-Operation Agreement between the IEEE and the NATO Standardization Agency (NSA) signed in May 2009, which resulted in the military standard IEEE-C95.2345-2014. He is currently participating in the drafting of technical guidelines for the implementation of German EMF workplace Ordinance.

JERROLD BUSHBERG is currently a Clinical Professor of radiology and radiation oncology with the U.C. Davis School of Medicine. He is the Director Emeritus of the Medical/Health Physics Programs. He retired as an Associate Chair of the Department of Radiology in 2018. He served as an Executive Officer of the Chemical/Biological/Nuclear Technical Unit 120 Pacific, a military emergency response and advisory team. He is a former Commander with the U.S. Naval Reserve, CDR. He was a member of Radiology Faculty, Yale School of Medicine. With over 40 years of experience, he has served as a Subject Matter Expert and an Adviser to government agencies and organizations, including the U.S. Department of Homeland Security, the FDA Center for Devices and Radiological Health, the WHO, and the IAEA in the areas of ionizing and nonionizing radiation protection, risk communication, medical physics, and radiological emergency medical management. He is an expert on biological effects, safety, and interactions of ionizing and nonionizing radiation, and he holds multiple radiation detection technology patents. In 2016, he was an appointed Vice-Chair of COMAR, Technical Committee of IEEE EMBS. He is the Chair of the Board of Directors and the Senior Vice President of NCRP. He serves as the Director and the Vice-Chair of The American Board of Medical Physics. He has been responsible for medical postgraduate education in medical physics, radiation biology, and protection for more than 35 years. He is an elected Fellow of the American Association of Physicists in Medicine and the Health Physics Society, certified by several national professional boards with subspecialty certification in radiation protection and medical physics. In 2014, he received the NCRP Warren K. Sinclair Medal for Excellence in Radiation Science and the Professor John C. Christiansen Distinguished Alumnus Award from the Purdue University School of Health Sciences, in 2016.

CHUNG-KWANG CHOU (S'72–M'75–SM'86–F'89–LF'12) received the B.S. degree from National Taiwan University, Taipei, in 1968, the M.S. degree from Washington University, St. Louis, MO, USA, in 1971, and the Ph.D. degree from the University of Washington, Seattle, in 1975. He is currently retired and an Independent Consultant on EMF safety issues. He spent a year as a National Institutes of Health's Postdoctoral Fellow with the Regional Primate Research Center and with the Department of Physiology and Biophysics, University of Washington, where he was a Faculty Member with the Department of Rehabilitation Medicine and the Center for Bioengineering, from 1977 to 1985. From 1985 to 1998, he was a Research Scientist and the Director of the Department of Radiation Research, City of Hope National Medical Center, Duarte, CA, USA. In April 1998, he joined Motorola as the Director of the Corporate EME Research Laboratory, and later became the Chief EME Scientist responsible for RF product safety. From February 2009 to December 2013, he was the Chief EME Scientist of Motorola Solutions. In 2006, he received the highest honor d'Arsonval Medal from the Bioelectromagnetics Society. He was on the Board of Directors of the Bioelectromagnetics Society, from 1981 to 1984, and served as the Chairman of IEEE/EMBS Committee on Man and Radiation, from 1996 to 1997. He was the Co-Chairman of the IEEE Scientific Coordinating Committee 28, Subcommittee 4 on RF Safety Standard, from 1997 to 2005, the Vice-Chairman of Committee 89-5 of the National Council on Radiation Protection and Measurements, from 1996 to 1999, and a Council Member of NCRP, from 1998 to 2004. He has been on the Advisory Panel of Non-Ionizing Radiation of NCRP, since 2016, and a Distinguished Lecturer of the IEEE Broadcast Technology Society, since 2016. He has been the Chairman of TC 95 of the International Committee on Electromagnetic Safety of IEEE, since 2006, responsible for exposure standards from 0 to 300 GHz. He was an Associate Editor of *Bioelectromagnetics*, from 1987 to 2003.

ROBERT CLEVELAND received the B.S. degree in physics from Virginia Tech and the M.S. and Ph.D. degrees in biophysics from Pennsylvania State University. In 2007, he retired from the Federal Communications Commission, where he had worked for 27 years. He was responsible for coordinating FCC environmental health and safety policy related to human exposure to radiofrequency (RF) energy. Prior to joining FCC, he was with Temple University and as an Environmental Consultant. He is a Telecommunications Consultant specializing in electromagnetic fields and safety. He is the author or coauthor of numerous scientific publications, articles, and government reports. His background includes research and teaching in radiation biology, biophysics, microbiology, physics, and engineering. In 2007, he was elected as a Fellow of the American Association for the Advancement of Science (AAAS). He is a member of the IEEE's International Committee on Electromagnetic Safety (ICES). He has received many awards. He has participated in many scientific committees and conferences and has served on the Board of Directors of the Bioelectromagnetics Society.

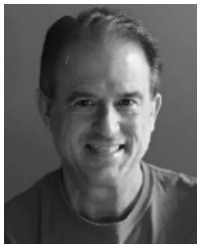
ANTONIO FARAONE (M'97–SM'05) was born in Rome, Italy, in 1966. He received the Research Doctorate (Ph.D.) degree in applied electromagnetics from the University of Rome "La Sapienza," in 1997. He joined the Motorola's (now Motorola Solutions, Inc.) Corporate Electromagnetic Energy (EME) Research Laboratory, Fort Lauderdale, FL, USA, involved in mobile antenna technology R&D, RF dosimetry research, and RF exposure safety and product compliance standards development in the IEEE and IEC. At Motorola Solutions, he currently serves as the Motorola Solutions Chief EME Scientist overseeing product RF exposure compliance. He was appointed Scientific Advisory Board Associates (SABA) Member, a Dan Noble Fellow, and a Master Innovator, holding 39 patents mostly in antenna technologies, and has coauthored 37 refereed journal publications. He also serves as the Chairman of the Board of the Mobile and Wireless Forum, an international industry association supporting research into RF health and safety and promoting device integrity and accessibility.



KENNETH R. FOSTER (M'77–SM'81–F'88–LF'13) received the Ph.D. degree in physics from Indiana University, Bloomington, IN, USA, in 1971. He was with the Naval Medical Research Institute, U.S. Navy, Bethesda, MD, USA, from 1971 to 1976. Since 1976, he has been with the Department of Bioengineering, University of Pennsylvania, Philadelphia, PA, USA, where he is currently a Professor Emeritus. He has been involved in studies on the interaction of nonionizing radiation and biological systems, including mechanisms of interaction and biomedical applications of radiofrequency and microwave energy. In addition, he has written widely about scientific issues related to possible health effects of electromagnetic fields. He has authored approximately 160 technical articles in peer-reviewed journals, numerous other articles, and two books related to technological risk and the law. He is a longtime member of TC 95 of the IEEE International Committee on Electromagnetic Safety and a member of the Physical Agents Committee of the American Conference of Governmental Industrial Hygienists, among many other professional activities. In 2016, he received the d'Arsonval Award from the Bioelectromagnetics Society for contributions to the field of bioelectromagnetics. He is a Co-Editor-in-Chief of *BioMedical Engineering OnLine*. He has been active for many years on the IEEE EMBS Committee of Man and Radiation, the IEEE Society on Social Implications of Technology, and the IEEE Engineering in Medicine and Biology Society.

KENNETH E. GETTMAN received the B.S. degree in engineering (biomedical) from Northwestern University, in May 1975, and the M.B.A. degree in technology management from IIT, in June 1988. He retired as the Director of International Standards for the National Electrical Manufacturers Association. From 1975 to 1979, he was with the U.S. Navy, serving on the USS Wainwright and for COMDESRON 4, as an Engineering Electrical Officer, a Communications Officer, a Dry Dock Safety Officer, and a Personnel Officer. From 1994 to 2019, he worked at NEMA where he was responsible for coordinating NEMA IEC activities; for USNC efforts in IEC TC16, TC17, SC17A, SC17B, SC17C, SC17D, TC22, SC22G, TC23, SC23E, TC44, TC64 SC65B/WG7, and TC106; and for coordinating NEMA positions on LVDC, harmonic current emissions, EMC, and EMF. He served as the IEC Secretary for Subcommittee 22G, and NEMA Staff for drives and PLC committees, including the International and Regional Standardization Committee. He was a U.S. Expert Member of the following committees within IEC: SC17B, SC23E, TC 64, and SC65B. He also participated in the USNC committees for IEC TC1, TC3, TC8, TC109, and TC111. He worked for Underwriters Laboratories as an Engineering Group Leader/Staff Engineer for wiring devices, medical equipment, electrified partition systems, lighting equipment, and industrial control equipment. He is a Registered Professional Engineer in Illinois and has CQE certification from ASQC. He was responsible for product certifications, standards development, and engineer training and also coordinated laboratory operations IAW ISO 25.

KEVIN GRAF received the B.S. degree *(summa cum laude)* in electrical and computer engineering from Cornell University, in 2007, and the M.S. and Ph.D. degrees in electrical engineering from Stanford University, in 2010 and 2014, respectively. He worked at Exponent, from 2014 to 2019, specializing in the analysis of electric and magnetic fields and waves, including analysis of consumer electronics, medical devices, high voltage transmission lines, and natural emissions, with comparisons to guidelines for electromagnetic exposure, interference, and compatibility. He is a licensed Professional Engineer in the state of California. Since 2017, he has been a Co-Chair of IEEE ICES TC95-SC3, the subcommittee of the International Committee on Electromagnetic Safety that focuses on safety levels with respect to human exposure to 0–3 kHz electromagnetic fields.



TIM HARRINGTON received the B.S.E.E. and M.S.E.E. degrees in applied electromagnetics from the University of Houston. He is a Senior Electronics Engineer with the Federal Communications Commission Office of Engineering and Technology Laboratory Division. His main responsibilities at the FCC OET Laboratory, Columbia, MD, USA, are for EMC, radio parameters, and human exposure (SAR and MPE) regulatory compliance and testing issues in radio device approvals. Before joining the FCC Laboratory, in 2001, he was involved in antenna design, computer simulation, and testing with Allgon Telecom, Fort Worth, TX, USA. Prior to this, he did design, testing, computer simulation, calibration, and applications development for various electromagnetic compatibility (EMC) test antennas, field probes, and test chambers at EMCO/Electro-Mechanics Co. (now ETS-Lindgren), Austin, TX, USA. Since the mid-1990s, he has been very active in various international standards committees (IEEE Standards 1528 and 1309, IEC CISPR/A, TC 106, and SC 77B, and ASC C63), preparing requirements and procedures for SAR and EMC compliance testing.

AKIMASA HIRATA (S'98–M'01–SM'10–F'17) received the B.E., M.E., and Ph.D. degrees in communications engineering from Osaka University, Suita, Japan, in 1996, 1998, and 2000, respectively. From 1999 to 2001, he was a Research Fellow of the Japan Society for the Promotion of Science and also a Visiting Research Scientist with the University of Victoria, Victoria, BC, Canada, in 2000. In 2001, he joined the Department of Communications Engineering, Osaka University, as an Assistant Professor. In 2004, he was an Associate Professor with the Nagoya Institute of Technology, where he is currently a Professor (Director). His research interests include electromagnetics and thermodynamics in biological tissue, waveguide analysis, EMC and EMI, and computational techniques in electromagnetics. He is an Editorial Board Member of *Physics in Medicine and Biology*, a member of the main commission and the Chair of the Project Group of International Commission on Non-Ionizing Radiation Protection, a Subcommittee Chair of the IEEE International Committee on Electromagnetic Safety, and an Expert of the World Health Organization. He is a Fellow of the Institute of Physics and a member of IEICE, IEE Japan, and Bioelectromagnetics Society. He received several awards, including Prizes for Science and Technology (for research category, in 2011, and public understanding promotion category, in 2014) by the Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science, and Technology, Japan, and the IEEE EMC-S Technical Achievement Award, in 2015, and the Japan Academy Medal, in 2018. From 2006 to 2012, he was also an Associate Editor of the IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING.

ROBERT (ROB) KAVET (M'10–SM'16) was born in Brooklyn, NY, USA, in October 1944. He received the master's degree in electrical engineering from Cornell University, in 1967, and the master's degree in environmental health sciences and the Ph.D. degree in respiratory physiology from the Harvard School of Public Health, in 1972 and 1977, respectively. He is currently an Instructor with the Harvard T.H. Chan School of Public Health, Boston. He has been involved in EMF health and safety issues since joining the Electric Power Research Institute (EPRI) as a Project Manager, in 1978. Since then, he served for a total of nearly 30 years at EPRI, retired, in 2016, as a Senior Technical Executive. His career at EPRI was committed to managing, designing, and participating in EMF health and safety research spanning the non-ionizing spectrum from direct current (dc) through power frequencies to radiofrequencies (RF). He was involved intimately with studies that included the areas of epidemiology, exposure assessment, laboratory studies (*in vivo* and *in vitro*), dosimetry, and the instrumentation and development of modeling software. These studies covered key health and safety endpoints, including cancer and pregnancy outcome, as well as the basis for exposure limits as published by the International Commission on Non-Ionizing Radiation Protection and the IEEE. He has authored or coauthored about 100 peers-reviewed publications concerned with the above-mentioned EMF topics. He is currently serving as the Co-Chair of Subcommittee 3 of IEEE's International Committee on Electromagnetic Safety (ICES) concerned with establishing exposure standards for frequencies between 0 and 5 MHz.

JAFAR KESHVARI received the degree in engineering from METU University, Ankara, Turkey, in 1989, and the M.Sc. and Ph.D. degrees in biomedical engineering from the Tampere University of Technology, in 1994 and 1997, respectively. He is currently serving as the Chairman of the IEEE International Committee for Electromagnetic Safety (ICES) and as the Adjunct Professor of bio-electromagnetics with Aalto University, Helsinki, Finland. He is also leading Intel's international standards activities. His biomedical engineering research has been dealt with the mathematical solution of the eye generated electrical signals, registering for the first time the magneto-retinogram (MRG) of the human eye and examining the characteristics of electro-oculogram (EOG) and eye movements. He has been involved in electromagnetic fields and health-related standardization, research, and education, since 2000. Besides his involvements at IEEE/ICES, he has been leading major international EMF compliance assessment activities at IEC, IEEE, and ITU. Under his leadership among other EMF standards, SAR assessment standards for wireless communication devices are globally harmonized.

BERTRAM JON KLAUENBERG (M'86–SM'17) was born in Baltimore, MD, USA, in August 1947. He received the dual B.S. degree in psychology anthropology from Towson University, Baltimore, in 1972, the M.A. degree in physiological psychology, in 1977, and the interdisciplinary Ph.D. degree in neuropsychology and human physiology from Wayne State University, Detroit, MI, USA, in 1980. He served as a Navigational Aids Electronics Technician in the U.S. Navy. He was a Postdoctoral Fellow, from 1980 to 1983, and a Research Associate of psychology–pharmacology with the University of Minnesota, Minneapolis, MN, USA, from 1983 to 1986, publishing research on behavioral toxicology, including the first report of thermal epileptic kindling. He joined the Air Force at Brooks AFB, San Antonio, TX, USA, in 1986. He conducted research into the biological effects of high-power microwaves and was a Senior Research Physiologist with the Air Force Research Laboratory (AFRL), Radio Frequency Bioeffects Branch, until retirement on December 2018. He identified military operational impacts of EMF limits and with IEEE ICES developed alternatives. He engineered a NATO-IEEE Technical Cooperation Agreement, initiating the first civilian development of a military workplace EMF exposure standard. He led several NATO Research Technology Organization task groups on EMF bioeffects reaching consensus for eliminating High Peak Power Ultra-Short Electromagnetic Pulses (HPP-EMP) limits. Consequently, the IEEE C95.1–2345-2014 followed suit and dropped the restriction on HPP-EMP. He organized/directed NATO Advanced Research Workshops, RF Standards and RF Dosimetry. He was the USAF and NATO liaison to the International Advisory Committee of the World Health Organization EMF Project, coordinated AFRL as a WHO collaborating institution for EMF and led two re-designations establishing international collaborative research/development. He initiated/led for 21 years the DoD Defense Standardization Program Radiofrequency Exposure to Personnel Safety as the Lead Standardization Activity. He received the IEEE International Award, for 2011 and 2006, and the 2012 DOD Defense Standardization Program Office (DSPO) Award. In 2016, he also received the DSPO highest award for achievements in standardization.

ALEXANDRE LEGROS was born in Versailles, France, in 1976. He received the Ph.D. degree in human movement sciences, in 2004, and completed a first postdoctoral fellowship on electrical deep brain stimulation (DBS) in dystonic syndromes at the Neurosurgery, Guy de Chauliac Hospital, Montpellier, France. He also completed a second postdoctoral fellowship in the Bioelectromagnetics Group, Lawson, from 2005 to 2007, where he was a Scientist, in September 2007. He is the Director of the Bioelectromagnetics and Human Threshold Research Group, Lawson Health Research Institute, London, ON, Canada, and an Associate Professor with the Departments of Medical Biophysics, Medical Imaging, and Kinesiology, Western University, Canada. He is also an Associate Scientist with the EuroStim/EuroMov, University of Montpellier, France, where he is duplicating his Canadian laboratory to develop new collaborative research projects involving human responses to high levels of ELF-MF. He has expertise in the fields of neurosciences, kinesiology, and biophysics applied to the study of neurostimulation and neuromodulation. His research interests mainly relate to the effects of specific electric and magnetic stimuli (DBS, transcranial magnetic stimulation, and time-varying magnetic fields) on human brain processing, motor control, and cognitive functions. He was a Board Member, from 2013 to 2015. He was the Chair of the Local Organising Committee for BioEM2019. He is currently a Secretary of the Board of Directors of the Bioelectromagnetics Society (BEMS) and is a Technical Program Committee Co-Chair for BioEM2020. He is the Canadian Chair for URSI commission K and the Chair of the Non-Ionizing Radiations Task Group, IRPA (International Radio Protection Association). He is also currently Co-Chairing a working group within the IEEE-ICES TC95 Subcommittee 6 and Chairing a task force on low frequencies recommendations.

DAVID P. MAXSON is an IEEE Wireless Communications Professional with extensive experience in evaluating and managing human exposure to electromagnetic energy in the built environment. He was a Vice-President and the Director of Engineering and technical operations with Charles River Broadcasting Company, Waltham, MA, USA, where he served for 20 years. In 1982, he founded the Broadcast Signal Laboratory, which has been providing broadcasters in the northeastern USA with precision frequency and modulation measurements traceable to the National Institute of Standards and Technology. With Broadcast Signal Laboratory and its successor, Isotrope, LLC, he has performed numerous workplace and public space hazard assessments of potential human exposure to radiofrequency energy and composed and implemented RF safety programs. He wrote *The IBOC Handbook: Understanding HD Radio Technology* (Focal Press, 2007) and has written chapters for the *NAB Engineering Handbook* 10th and 11th Editions. He is a Corresponding Member of the IEEE-USA Committee on Communications Policy. He is a frequent Lecturer at the National Association of Broadcasters Broadcast Engineering Conference, presenting peer-reviewed technical articles on radio frequency signal measurement technique.

JOHN M. OSEPCHUK (A'51–M'56–SM'71–F'78–LF'93) received the A.B., A.M., and Ph.D. degrees from Harvard University, in 1949, 1950, and 1957, respectively. He was with Raytheon Company, where he was involved with microwave research and development (i.e., ferrites, plasmas, tubes, and heating systems). He retired from Raytheon, in 1995, and since then, he has been a Consultant with Full Spectrum Consulting. He has authored numerous publications and holds numerous patents, including one on microwave oven door seal design. He was an Officer of the Electromagnetic Energy Association (EEA) and an early member of the Bioelectromagnetics Society. He continues to work to strengthen the world-wide influence of the International Committee on Electromagnetic Safety (ICES). He is a member of Phi Beta Kappa and Sigma Xi. He was a recipient of the 1998 IEEE Standards Medallion and the 2000 IEEE Millennium Medal. He has contributed to the founding and operating many IEEE activities, e.g., Life Member of COMAR and the Chairman IEEE MTT-S and SIT-S. He was the President of IMPI and an Editor of *Journal of Microwave Power*.

J. PATRICK REILLY (F'98) received the B.E.E. degree in electrical engineering from the University of Detroit, in 1962, and the M.S.E. degree in electrical engineering and applied science from George Washington University, in 1966. He retired, in 2011, from the Johns Hopkins University Applied Physics Laboratory (APL), where he performed research in a variety of disciplines, including theoretical and experimental work in bioelectricity. His other fields of research over his 50-year career at APL included electromagnetic interactions with the natural environment, signal processing, radar, underwater acoustics, human acoustic perception, infrared technology, and the transit navigation system, the precursor of modern satellite navigation. As the President of Metatec Associates, which he founded in 1986, he does research and consulting related to bioelectric phenomena, bioelectric devices, and electrical and electromagnetic safety. In this role, he consults with international federal, state, and private agencies concerning exposure to electric current and electromagnetic fields, including the analysis of bioelectric therapy and diagnosis, electrical safety, and forensic science. He is the author or coauthor of over 160 publications, including one book on radar and three on bioelectric phenomena and electrical safety. His book, *Applied Bioelectricity*, is a standard reference in the field of electrostimulation. In 2012, he published a memoir, Snake Music, through Lulu Press, Inc. In 2017, he received the prestigious D'Arsonval Award of the Bioelectromagnetics Society. The award was conferred in Montpellier, France, in 2019. He was a Principal Author of the IEEE Standard C95.6, published by the IEEE's International Committee on Electromagnetic Safety (ICES), in 2002.

RICHARD (RIC) A. TELL (M'70–SM'81–LSM'10–LF'12) was born in Roscoe, TX, USA, on January 25, 1944. He received the B.S. degree in physics from Midwestern State University, Wichita Falls, TX, USA, in 1966, and the M.S. degree in radiation sciences from Rutgers University, New Brunswick, NJ, USA, in 1967. He has 52 years of experience working on radio frequency safety issues, first at the U.S. Environmental Protection Agency for 20 years, where he served as the Chief of the agency's Electromagnetics Branch, and since then in his own scientific consulting business. His specialty areas include RF safety, RF field exposure assessment, antenna analysis, and field measurements. Much of his work has been in helping clients to evaluate compliance with applicable standards and establish RF safety programs within their companies. He has been an elected member of the National Council on Radiation Protection and Measurements (NCRP) and serves as the Chairman of Subcommittee 2 of the IEEE International Committee on Electromagnetic Safety (ICES) TC95 that published the IEEE Std C95.7 Recommended Practice for RF Safety Programs and IEEE Std C95.2 on Radio Frequency Energy and Current-Flow Symbols. He is the Chairman of the IEEE/EMBS Committee on Man and Radiation (COMAR) and serves on the NCRP Advisory Panel on Nonionizing Radiation. He was a recipient of the 2019 Non-Ionizing Radiation Distinguished Service Award from the Health Physics Society.

ARTNARONG THANSANDOTE (S'75–M'81–SM'91–LSM'16) was born in Chumphon, Thailand. He received the B.Eng. (Hons.) degree in electrical engineering from Khon Kaen University, Thailand, in 1973, the M.Sc. degree in agricultural engineering from the University of Manitoba, Canada, in 1976, and the Ph.D. degree in electrical engineering from Carleton University, Canada, in 1982. From 1973 to 1988, he held teaching positions at Khon Kaen University as a Lecturer, an Assistant Professor, and then as an Associate Professor in electrical engineering. From 1988 to 1991, he was a Research Associate and a part-time Lecturer in electrical engineering with the University of Ottawa, Canada. His research involved in the development of broadband electronic and fiber-optic sensors for the measurement of transient/pulsed electromagnetic fields (EMFs). In July 1991, he joined Health Canada as a Research Scientist and later served as a Chief of the Electromagnetics Division. He retired in September 2012 but still maintains a professional association with Health Canada as a Scientist Emeritus of the Consumer and Clinical Radiation Protection Bureau. During his tenure as a Division Chief, he was part of the team which carried out studies in the areas related to EMF bio-effects and exposure assessment, and developed guidelines, commonly known as Safety Code 6, for human exposure to radiofrequency (RF) electromagnetic energy. He was a member of the International Advisory Committee of the WHO International EMF Project, from 1996 to 2011, and a member of the Board of Directors of the Bioelectromagnetics Society, from 2008 to 2011, and has served the IEEE/ICES/TC95 as a Co-Chair of Subcommittee 4, which develops RF exposure standards, since 2005. He is currently a Technical Advisor with the Office of the National Broadcasting and Telecommunications Commission, Thailand, to provide advice concerning RF exposure assessment and possible health risks from RF exposure.

KENICHI YAMAZAKI (M'95–SM'06) was born in Yokohama, Japan, in February 1968. He received the B.S. degree in applied physics from the Tokyo University of Science, Tokyo, Japan, in 1990, and the M.S. and Ph.D. degrees in biomedical engineering from Hokkaido University, Sapporo, Japan, in 1992 and 2001, respectively. In 1992, he joined the Central Research Institute of Electric Power Industry (CRIEPI), Tokyo. In 2002 and 2003, he was a Visiting Scientist with the School of Electrical Engineering and Computer Science, Washington State University, Pullman, WA, USA. He is currently a Deputy Associate Vice-President and the Leader of the Surge and Electromagnetic Phenomena Research Section, CRIEPI, Yokosuka, Japan. His research interests include the characterization of human exposure to low-frequency electromagnetic fields and power line electromagnetic compatibility. He is a member of the Bioelectromagnetics Society.

MARVIN C. ZISKIN (M'69–SM'74–F'03–LSM'01–LF'03) received the A.B. and M.D. degrees from the Temple University School of Medicine, Philadelphia, and the M.S.Bm.E. degree in bioengineering from Drexel University. From 1965 to 1966, he was a Research Associate in diagnostic ultrasound with the Hahnemann Medical College. Following a two-year tour duty at the U.S. Air Force Aerospace Medical Research Laboratories, he returned to Temple University, in 1968, where, for the past 23 years, he has served as the Director of the Center for Biomedical Physics. From 1982 to 1984, he was the President of the American Institute of Ultrasound in Medicine (AIUM), and from 2003 to 2006, he was the President of the World Federation of Ultrasound in Medicine and Biology (WFUMB). He is a Professor Emeritus of radiology and medical physics with the Temple University School of Medicine, Philadelphia. His interest in ultrasound, image processing, and non-ionizing electromagnetic radiation has resulted in seven books and over 275 scientific publications. His research interests include many areas within biomedical engineering with a special interest in ultrasound, millimeter waves, and other non-ionizing radiation. He received the 2011 D'Arsonval Award of the Bioelectromagnetics Society. He is currently the Co-Chair of the IEEE International Committee for Electromagnetic Safety (ICES) TC95 Subcommittee SC4, which establishes safety standards for RF radiation. He has been on the Board of Directors of the Bioelectromagnetics Society and of the National Council for Radiation Protection and Measurements (NCRP). He has been active in a number of professional societies. He was the Chairman of the IEEE Committee on Radiation and Man (COMAR). He has served on the Editorial Boards of *Journal of Clinical Ultrasound*, *Clinical Diagnostic Ultrasound*, *Ultrasound in Medicine and Biology*, *Journal of Ultrasound in Medicine*, and *Bioelectromagnetics*.

PETER M. ZOLLMAN received the B.Sc. (Hons.) degree from the University College of North Wales, in 1979. He worked for Racal Communications, from 1979 to 1983. In 1983, he was a start-up employee with what is now Vodafone, developing drive-coverage measurement systems, systemizing RF coverage software, and developing on-frequency cellular repeaters and investigating interference issues. From 1990 to 1998, he worked on GSM handset type approval helping develop ETSI standards and certification of the interim and phase 1 type approval test systems. As a Project Manager, he managed GSM phase 2 type approval system development and certification at GSM Facilities Ltd. He Chaired the GSM Association Certification Task Force setting up the framework to evaluate new products on real networks. In 1998, he joined Vodafone U.K.'s Advanced Development Group (since 2001, Vodafone Group R&D), establishing the engineering and science aspects of the Vodafone Group RF safety policy. He helped to develop CENELEC EMF standards and was a Convener for IEC TC106 project team developing IEC 62232 Ed.1 and received the IEC 1906 Award, in 2011. He is a member of the Bioelectromagnetics Society, a Chartered Engineer, and a Fellow of the Institute of Engineering and Technology, in 2005. He Chaired the GSM Association EMF Expert Panel, from 2005 to 2013, initiating dosimetry research in support of standards. He Chaired the U.K. Mobile Operators' Association Science Working Group, from 2001 to 2013, liaising with the U.K. government to set up the Mobile Telecommunications and Health Research programs and with epidemiologists to identify the information needed from industry. Following his retirement from Vodafone, in 2013, he is currently providing consultancy on RF health and safety, remaining active on British Standard Institute GEL 106, and IEEE ICES and COMAR.