International Microwave Symposium
Virtual Event: 22 June 2021
PL4: Inter-Society Technology Panel (ISTP) Session on 5G Health Impact – Fiction or Facts?

Overview of the IEEE standards on human protection from electromagnetic fields

Dr. C-K. Chou*
TC95 Chairman
International Committee on Electromagnetic Safety (ICES)
Institute of Electrical and Electronics Engineers (IEEE)
Piscataway, NJ, USA

***Speaking as an individual and not for the IEEE**

EMF safety concerns

EMF Sources (year)

- Radar (50-60's)
- Radio and TV Broadcasting (60-70's)

- Microwave Oven (70-80's)

- Power line (80's - ?)

- Police Radar (80's)

- Wireless Communication (90's - ?)

(mobile phones 2-5 G, base stations, Wi-Fi, WiMAX, smart meters, RFID, etc.)

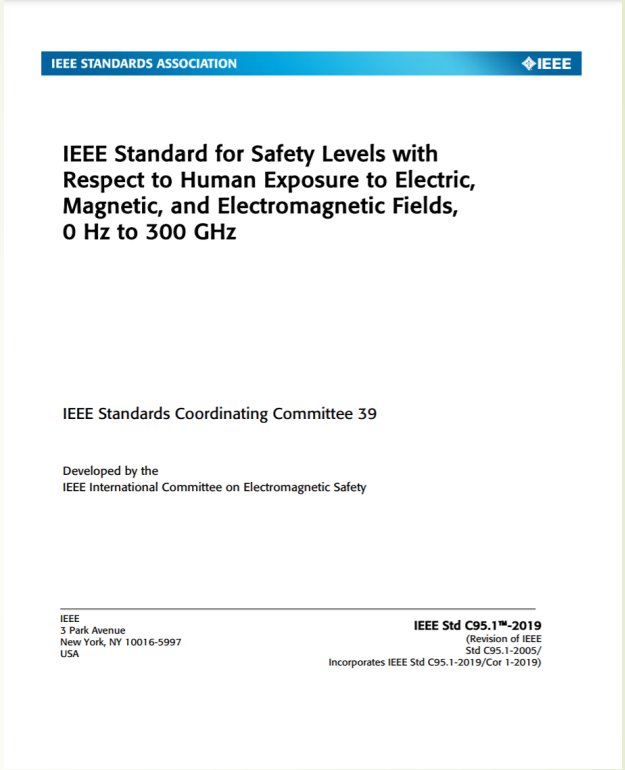
- Wireless power transmission (2012-?)

Steps to address safety concerns

Scientific research

Peer-reviewed publication

Consensus standards

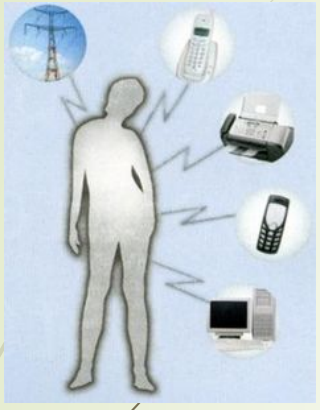


Regulations

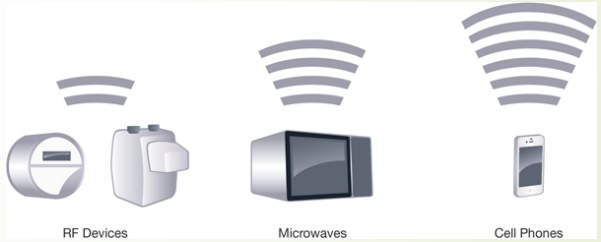
Standards

- Based on science
- Protective
- Practical to implement

Three Types of EMF Safety Standards

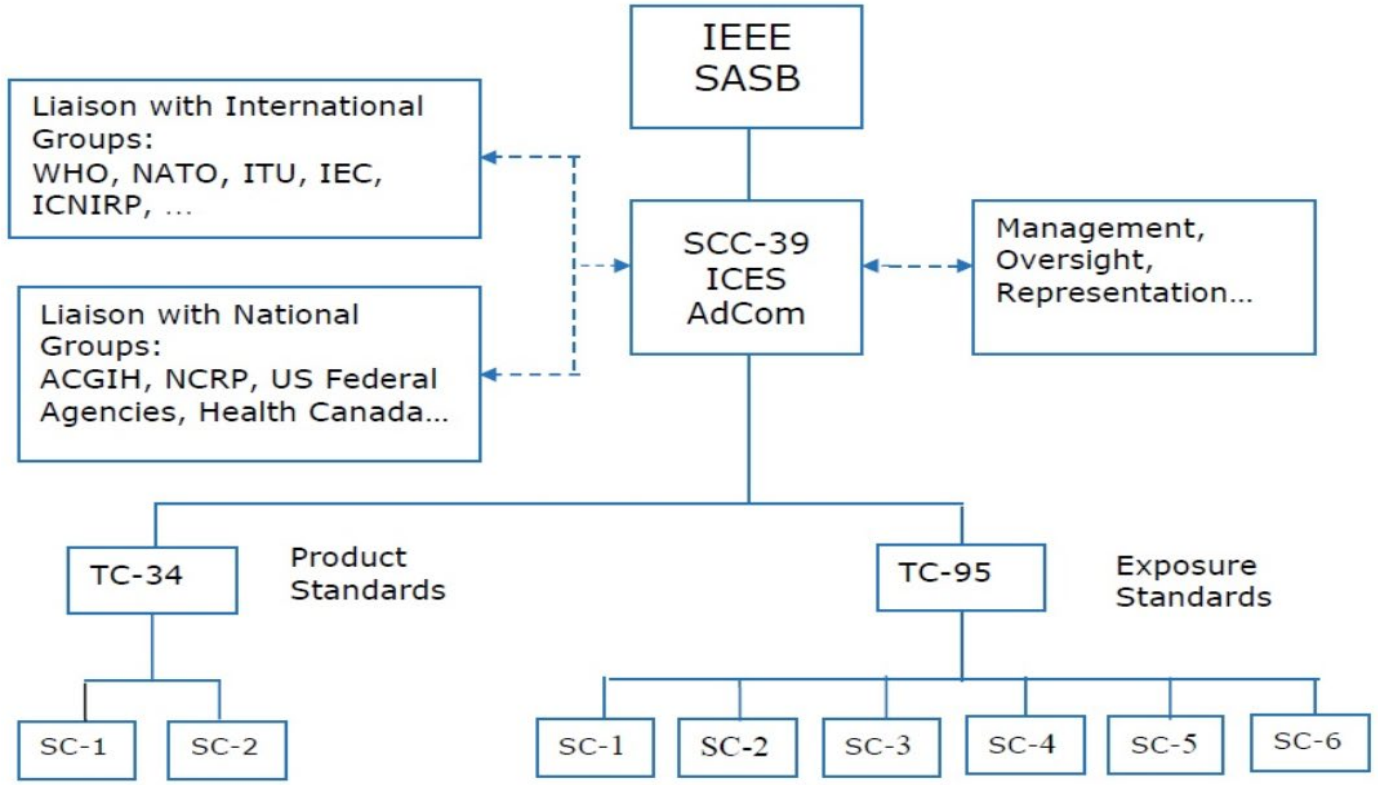


- Exposure standards for limiting human exposures
  - Two tiers
    - General public (unrestricted environments)
    - Occupational (restricted environments)
- Assessment standards for radiating source compliance
  - Measurements
  - Computations



- Interference standards with medical devices

IEEE Standards Coordinating Committee (SCC) 39 International Committee on Electromagnetic Safety (ICES)



TC-34

SC-1: Measurement Techniques
- WG-1: SAR-Handheld Devices

SC-2: Computational Techniques
- WG-1: General FDTD Requirements
- WG-2: Vehicle mounted antenna configurations
- WG-3: Mobile phones/personal wireless devices
- WG-4: General FEM Requirements

TC-95

SC-1: Measurements and Calculations
SC-2: Warning Signs, Hazard Communications
SC-3: Low-frequency Exposure Limits
SC-4: High-frequency Exposure Limits
SC-5: Electro-explosive Devices
SC-6: EMF Modeling and Dosimetry

IEEE Exposure Standards History

1960: USASI C95 Radiation Hazards Project and Committee chartered
1966: USAS C95.1-1966 (2 pages)
10 mW/cm^2 (10 MHz to 100 GHz)
based on simple thermal model
1974: ANSI C95.1-1974 (limits for E^2 and H^2)
1982: ANSI C95.1-1982 (incorporates dosimetry)
1991: IEEE C95.1-1991 (two tiers – reaffirmed 1997)
2002: IEEE C95.6-2002 (0-3 kHz)
2006: IEEE C95.1-2005 published on April 19, 2006 (comprehensive revision, 250 pages, 1143 ref.)
2014: IEEE C95.7-2014 safety program
2014: IEEE C95.1-2345-2014 (0-300 GHz) (NATO/IEEE agreement)
2015: NATO adopted C95.1-2345-2014
2019: IEEE C95.1-2019 (0-300 GHz) published on October 4, 2019
(310 pages, 1550 ref.) revised limits for 6 GHz – 300 GHz

IEEE EMF safety standards

- 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
- C95.7-2014 - IEEE Recommended Practice for Radio Frequency Safety Programs, 3 kHz to 300 GHz
- C95.1-2019 - IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz

Table 5 - DRLs (100 kHz to 6 GHz)

Conditions	Persons in unrestricted environments SAR (W/kg)[a]	Persons permitted in restricted environments SAR (W/kg)[a]
Whole-body exposure	0.08	0.4
Local exposure[b] (head and torso)	2	10
Local exposure[b] (limbs and pinnae)	4	20

[a] SAR is averaged over 30 min for whole-body exposure and 6 min for local exposure (see B.6 for averaging time).

[b] Averaged over any 10 g of tissue (defined as a tissue volume in the shape of a cube).[27]

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

Conditions	Epithelial power density (W/m^2)[a,b,c]	
	Persons in unrestricted environments	Persons permitted in restricted environments
Body surface	20	100

[a] Epithelial power density through body surface is averaged over 6 min.

[b] Averaged over any 4 cm^2 of body surface at frequencies between 6 GHz and 300 GHz (defined as area in the shape of a square at surface of the body).

[c] Small exposed areas above 30 GHz: If the exposed area on the body surface is small (< 1 cm^2 as defined by −3 dB contours relative to the peak exposure), the epithelial power density is allowed to exceed the DRL values of Table 6 by a factor of 2, with an averaging area of 1 cm^2 (defined as area in the shape of a square at the body surface).

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

Frequency range (MHz)	Electric field strength (E)[a,b,c] (V/m)	Magnetic field strength (H)[a,b,c] (A/m)	Power density (S)[a,b,c] (W/m^2)		Averaging time (min)
			S_E	S_H	
0.1 to 1.34	614	16.3 / f_M	1000	100 000 / f_M^2	30
1.34 to 30	823.8 / f_M	16.3 / f_M	1800 / f_M^2	100 000 / f_M^2	30
30 to 100	27.5	158.3 / $f_M^{1.668}$	2	9 400 000 / $f_M^{3.336}$	30
100 to 400	27.5	0.0729	2		30
400 to 2000	—	—	f_M / 200		30
2000 to 300 000	—	—	10		30

NOTE—S_E and S_H are plane-wave-equivalent power density values, based on electric or magnetic field strength respectively, and are commonly used as a convenient comparison with ERLs at higher frequencies and are sometimes displayed on commonly used instruments.

[a] For exposures that are uniform over the dimensions of the body, such as certain far-field plane-wave exposures, the exposure field strengths and power densities are compared with the ERLs in Table 7. For more typical nonuniform exposures, the mean values of the exposure fields, as obtained by spatially averaging the plane-wave-equivalent power densities or the squares of the field strengths, are compared with the ERLs in Table 7. (See notes to Table 7 through Table 11 in 4.3.5.)

[b] f_M is the frequency in MHz.

[c] The *E*, *H*, and *S* values are those rms values unperturbed by the presence of the body.

Table 9 - Local exposure ERLs (100 kHz to 6 GHz) persons in unrestricted environments

Frequency range (MHz)	Electric field strength (E) [a,b,c,d] (V/m)	Magnetic field strength (H) [a,b,c,d] (A/m)	Power density (S) [a,b,c,d] (W/m²)	
			S_E	S_H
0.1 to 1.34	1373	$36.4/f_M$	5000	$500\,000/f_M^2$
1.34 to 30	$1842/f_M$	$36.4/f_M$	$9000/f_M^2$	$500\,000/f_M^2$
30 to 100	61.4	$353/f_M^{1.668}$	10	$47\,000\,000/f_M^{3.336}$
100 to 400	$21.2 \times f_M^{0.232}$	$0.0562 \times f_M^{0.232}$	$1.19 \times f_M^{0.463}$	
400 to 2000	—	—	$1.19 \times f_M^{0.463}$	
2000 to 6000	—	—	40	

NOTE 1—Below 6 GHz, portable devices are typically tested for DRL compliance (e.g., SAR), for which distinct limits for head and torso, pinnae and limbs are defined.

NOTE 2— S_E and S_H are plane-wave-equivalent power density values, based on electric or magnetic field strength respectively, and are commonly used as a convenient comparison with ERLs at higher frequencies and are sometimes displayed on commonly used instruments.

[a] Determined in air at the location of the body surface.

[b] Spatial and temporal peaks averaged over 6 min.

[c] f_M is the frequency in MHz.

[d] The E, H and S values are those rms values unperturbed by the presence of the body.

[e] See notes to Table 7 through Table 11 in 4.3.5.

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

Frequency	Persons in unrestricted environments Incident Power Density (W/m^2)[a,b,c,d,e]	Persons in restricted environments Incident Power Density (W/m^2)[a,b,c,d,e]
6 GHz	40	200
6 GHz to 300 GHz	$55 f_G^{-0.177}$	$274.8 f_G^{-0.177}$
300 GHz	20	100

[a] Incident power density is averaged over 6 min for local exposure.

[b] Averaged over any 4 cm^2 of body surface for 6 GHz to 300 GHz (area defined as surface of the body in the shape of a square).

[c] Small exposed areas above 30 GHz: If the exposed area on body surface is small (<1 cm^2 as defined by −3 dB contours relative to the peak exposure), the incident power density is allowed to exceed the ERL values of Table 11 by a factor of 2, with an averaging area of 1 cm^2 (defined as area in the shape of a square at surface of the body).

[d] Assessed in air at the location of the body, but the body is absent during assessment.

[e] f_G is the frequency in GHz.

[f] See notes to Table 7 through Table 11 in 4.3.5.

ICES TC95 EMF Assessment standards

- **C95.3-2021**- IEEE Recommended Practice for Measurements and Computations of Electric, Magnetic, and Electromagnetic Fields with Respect to Human Exposure to Such Fields, 0 Hz to 300 GHz

- **P2889** - Draft Guide for the Definition of Incident Power Density to Correlate Surface Temperature Elevation (Being voted)

ICES TC34 EMF Compliance standards

- **IEEE/IEC 62209-1528-2020** - Measurement procedure for the assessment of specific absorption rate of human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices – Part 1528: Human models, instrumentation, and procedures (Frequency range of 4 MHz to 10 GHz)
- **IEEE/IEC 62704-1-2017** - Determining the Peak Spatial Average Specific Absorption Rate (SAR) in the Human Body from Wireless Communications Devices, 30 MHz - 6 GHz. Part 1: General Requirements for using the Finite Difference Time Domain (FDTD) Method for SAR Calculations
- **IEEE/IEC 62704-2-2017** - Determining the peak spatial-average specific absorption rate (SAR) in the human body from wireless communications devices, 30 MHz to 6 GHz -- Part 2: Specific requirements for finite difference time domain (FDTD) modelling of exposure from vehicle mounted antennas
- **IEEE/IEC 62704-3-2017** - Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Body from Wireless Communications Devices, 30 MHz - 6 GHz Part 3: Specific Requirements for Using the Finite Difference Time Domain (FDTD) Method for SAR Calculations of Mobile Phones
- **IEC/IEEE 62704-4-2020** - Determining the peak spatial-average specific absorption rate (SAR) in the human body from wireless communication devices, 30 MHz to 6 GHz – Part 4: General requirements for using the finite element method for SAR calculations
- **IEEE/IEC 62704-5** - Determining the power Density of the Electromagnetic Field Associated with Human Exposure to Wireless Devices Operating in Close Proximity to the Head and Body Using Computational Techniques, 6 GHz to 300 GHz Draft Standard

Free IEEE Safety Standards

Get IEEE C95™ STANDARDS: Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields https://ieeexplore.ieee.org/browse/standards/get-program/page/series?id=82

- C95.1-2019/Cor 2-2020 - IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz - Corrigenda 2
- C95.1-2019 - IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz
- 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
- C95.2-2018 - IEEE Standard for Radio-Frequency Energy and Current-Flow Symbols
- C95.3-2021 - IEEE Recommended Practice for Measurements and Computations of Electric, Magnetic, and Electromagnetic Fields with Respect to Human Exposure to Such Fields, 0 Hz to 300 GHz
- C95.7-2014 - IEEE Recommended Practice for Radio Frequency Safety Programs, 3 kHz to 300 GHz

Sponsored by the United States Navy, Air Force, and Army.

Thank You

Contact:
ck.chou@ieee.org