THE ANSI/IEEE RF SAFETY STANDARD AND ITS RATIONALE

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Introduction

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 (IEEE). This led to one of the earliest of the safety standards for the frequency band 300 kHz to 100 GHz issued in 1974 as follows:

> ANSI C95.1-1974 American National Standard Safety Level of Electro-magnetic Radiation with respect to personnel
>
> This standard was fairly simple with an incident power density limit of 10 mW/cm ^{2} regardness of frequency.

The C95.1-1982 Safety Standard

Major revisions in the 1974 standard were made in 1979 to take into account considerable expansion of the experimental data base [1], the recognition of whole body resonance of electromagnetic energy absorption [2] and the general advances in dosimetry of RF radiation [3]. This led to a frequency-dependent standard being issued as ANSI C95.1-1982 [1] in 1982. A major underpinning of the C95.1-1982 standard was the observation in several laboratories of behavioral disruption (task stoppage) of laboratory animals such as rats, monkeys, etc. for whole body averaged rates of electromagnetic energy absorption (specific absorption rates or SARs) of 4-8 W/kg in exposure times on the order of 30-60 minutes [1, 4, 5]. Even though these observed behavioral effects under acute exposures were fully reversible and the animals were capable of performing the same tasks under microwave exposure on subsequent days, it was argued that an acute reversible effect would lead to irreversible injury for chronic exposures at such whole-body-averaged SARs. The RF Protection Guide (RFPG) was, therefore, set to limit the whole-body-averaged SAR to 0.4 W/kg for all possible sizes and age groups of humans from children to adults. Dosimetric information on EM energy absorption in human beings [2, 3, 6, 7] was used to obtain the power density as a function of frequency so that under worst case exposures (incident electric field vector parallel to the length of the human body, grounded or ungrounded conditions), the whole-body-averaged SAR would be less than 0.4 W/kg. The ANSI/IEEE C95.1-1982 RF Safety Standard is shown graphically in Fig. 1 for power densities averaged over any 0.1 hour period and corresponding incident electric fields in the frequency range 300 kHz (0.3 MHz) to 100 GHz that should not be exceeded. The limiting magnetic field strengths in A/m at each of the frequencies (with H^2 averaged over any 0.1 hour period) are given by E/377 where E is the limiting electric field strength in V/m. Recognizing the highly non-uniform nature of SAR distribution, including some regions where there may be high local SARs e.g. the neck, the 1982 Standard further stipulated that the local SAR in any 1-g of tissue taken in the form of a cube averaged over any 0.1 hour period must not exceed 20 times the whole-body-averaged limit i.e. 8 W/kg [1].

The following exclusion clauses were also incorporated as a part of the ANSI/IEEE C95.1-1982 Safety Standard [1]:

1. At frequencies between 0.3 and 100,000 MHz, the safety limits shown graphically in Fig. 1 may be exceeded if the exposure conditions can be shown to produce SARs below 0.4 W/kg as averaged over the whole body and peak SAR values below 8.0 W/kg as averaged over any 1-g of tissue.

2. At frequencies between 0.3 and 1000 MHz, the safety limits shown in Fig. 1 may be exceeded if the RF input power of a radiating device is seven watts or less.

The ANSI/IEEE C95.1-1991 Safety Standard [8}

Additional research pointed out deficiencies in the ANSI C95.1-1982 Safety Standard particularly relating to the problems of RF shock and burn and significant induced RF currents for frequencies in the VLF-VHF range of frequencies [9]. Also RF magnetic fields were shown to couple less strongly than electric fields associated with incident EM waves [9]. The new safety standard approved by ANSI in 1992 [8] includes an expanded frequency range (3 kHz to 300 GHz), limits on induced body current to prevent RF shocks and burns, a relaxation of limits on exposure to magnetic fields at low frequencies (below 10 MHz) and exposure limits and averaging time at high frequencies that are compatible with existing infrared maximum permissible exposure (MPE) limits. A very important change in the new IEEE C95.1-1991 Safety Standard [8] is that it is a two-tier standard with distinction between controlled and uncontrolled environments, the latter for locations where there is exposure of individuals who have no knowledge or control of their exposure e.g. living quarters or work places that are not clearly identified. The maximum permissible exposures for controlled and uncontrolled environments are given in Tables 1 and 2, respectively. It can be seen that the MPEs for uncontrolled environments in Table 2 are lower than in controlled environments (Table 1) under certain conditions such as resonance or for situations with associated hazards such as RF shock or burn. Also as seen in the footnotes of Tables 1 and 2, the exposure values for electric and magnetic fields are obtained by spatially averaging over an area equivalent to the vertical cross section of the human body rather than the local values. This would, therefore, allow considerably higher limits when nonuniform, rather than uniform, whole-body exposures are involved with an upper limit that is not to exceed $20\ E^2$ .or $20\ H^2$ both for controlled and uncontrolled environments. This relaxation of exposure, however, does not apply for exposure of the eyes and the testes since these organs are not as well perfused as the rest of the body. Furthermore, because of lack of scientific data on the transient discharge energies required for startle reactions, the current limits given in Parts B of Tables 1 and 2 are for continuous contact rather than intermittent contacts.

As in the 1982 Safety Standard, upper limits are placed on the whole-body-averaged and peak 1-g local SARs. For controlled environments at frequencies between 100 kHz and 6 GHz, the MPE of Table 1 may be exceeded provided it is shown by appropriate techniques to produce a whole-body-averaged SAR of no more than 0.4 W/kg and peak local SAR of no more than 8 W/kg for any 1-g of tissue (defined as a tissue volume in the shape of a cube) except for the hands, wrists, and ankles where the peak 1-g SAR shall not exceed 20 W/kg. The SAR limits in this range of frequencies between 100 kHz and 6 GHz are five times lower for uncontrolled environments. The MPEs given in Table 2 in this frequency region may thus be exceeded provided it can be shown by appropriate (numerical or experimental) techniques to produce a whole-body-averaged SAR of less than or equal to 0.08 W/kg and peak local SAR of no more than 1.6 W/kg for any 1-g of tissue (defined as a tissue volume in the shape of a cube) except for the hands, wrists, and ankles where the peak 1-g SAR shall not exceed 4 W/kg.

For simultaneous exposure at a number of frequencies for which there are different values of MPE (in Tables 1 or 2 as appropriate), the fraction of the MPE in terms of E^2 or H^2 or power density S incurred for each of the frequencies should be determined, and the sum of all such fractions should not exceed unity both for controlled and uncontrolled environments.

For exposures to pulsed RF fields in the frequency range 0.1 to 300,000 MHz, the temporal peak value of E-field should not exceed 100 KV/m for controlled or uncontrolled environments.

Concluding Remarks

Following the lead of ANSI/IEEE C95.1-1982 Standard back in 1982, the safety standards all over the western world were altered to frequency-dependent exposure limits that recognized resonance of the human body, and limited exposures to whole-body- averaged SARs of 0.4 W/kg for occupational exposures and 0.08 W/kg for general public exposures. Of note here are the standards suggested by IRPA of WHO, NRPB in U.K., standards in Canada, Australia, Germany, Japan, Scandinavia and elsewhere back in mid-to-late 1980's. Because of the more recent research on the problems relating to RF shock and burn and significant induced RF currents for frequencies in the VLF-VHF range of frequencies, these standards are now being revised to also incorporate limits on induced currents. Some of the recently revised standards are listed in the following for possible further reading:

1. ICNIRP (International Commission on Non-Ionizing Radiation Protection), "Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (Up to 300 GHz)," *Health Physics*, Vol. 74(4), pp. 494-522, April 1998.

2. AS/NZS 2772.1 (Int): 1998, "Interim Australian/New Zealand Standard, Radiofrequency Fields, Part 1: Maximum Exposure Levels - 3 kHz to 300 GHz," published by Standards Australia, The Crescent, Homebush NSW 2140, Australia.

3. Canadian Safety Code 6, "Limits of Human Exposure to Radiofrequency Electromag netic Fields in the Frequency Range from 3 kHz to 300 GHz," *Environmental Health Directorate,* Health, Canada, Ottawa, Canada, 1998.

4. NRPB, “Board Statement on Restrictions on Human Exposure to Static and Time-Varying Electromagnetic Fields and Radiation,” Vol. 4, No. 5, National Radiological Protection Board, Chilton, Didcot, Oxon, U.K., 1993.

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1. ANSI C95.1-1982, “American National Standard Safety Levels With Respect to Human Exposure to Radiofrequency Electromagnetic Fields, 300 kHz to 100 GHz,” The Institute of Electrical and Electronics Engineers, Inc., 345 East 47th Street, New York, NY 10017.

2. O. P. Gandhi, “Conditions of Strongest Electromagnetic Power Deposition in Man and Animals,” *IEEE Transactions on Microwave Theory and Technique*s, Vol. 23, pp. 1021-1029, 1975.

3. C. H. Durney, H. Massoudi, and M. F. Iskander, *Radiofrequency Radiation Dosimetry Handboo*k, (Fourth Edition), Report USAFSAM-TR-85-73, USAF School of Aerospace Medicine, Brooks AFB, TX 78235, 1986.

4. J. A. D’Andrea, O. P. Gandhi, and J. L. Lords, “Behavioral and Thermal Effects of Microwave Radiation at Resonant and Non-Resonant Wavelengths,” *Radio Scienc*e, Vol. 12(6S), pp. 251-256, 1977.

5. D. R. Justesen, “Behavioral and Psychological Effects of Microwave Radiation,” *Bulletin of the New York Academy of Medicin*e, Vol. 55, pp. 1058-1078, 1980.

6. O. P. Gandhi, “State of the Knowledge for Electromagnetic Absorption in Man and Animals,” *Proceedings of the IEE*E, Vol. 68(1), pp. 24-32, 1980.

7. C. H. Durney, “Electromagnetic Dosimetry for Models of Humans and Animals: A Review of Theoretical and Numerical Techniques,” *Proceedings of the IEE*E, Vol. 68(1), p. 33-40, 1980.

8. IEEE C95.1-1991 (Approved by ANSI in 1992), “IEEE Standard for Safety Levels With Respect to Human Exposure to Radiofrequency Electromagnetic Fields, 3 kHz to 300 GHz,” The Institute of Electrical and Electronics Engineers, Inc., 345 East 47th Street, New York, NY 10017.

9. O. P. Gandhi, “ANSI Radiofrequency Safety Guide: Its Rationale, Some Problems and Suggested Improvements,” Chapter 3, pp. 28-46, in *Biological Effects and Medical Applications of Electromagnetic Energ*y, edited by O. P. Gandhi, Prentice Hall Inc., Englewood Cliffs, NJ, 1990.

Table 1. Maximum Permissible Exposure for Controlled Environments [8].

Part A
Electromagnetic Fields *

1 Frequency Range (MHz)	2 Electric Field Strength (E) (V/m)	3 Magnetic Field Strength (H) (A/m)	4 Power Density (S) E-Field, H-Field (mW/cm^2)	5 Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
0.003 - 0.1	614	163	(100, 1000000)†	6
0.1 - 3.0	614	16.3/f	(100, $10000/f^2$)†	6
3 - 30	1842/f	16.3/f	($900/f^2$, $10000/f^2$)†	6
30 - 100	61.4	16.3/f	(1.0, $10000/f^2$)†	6
100 - 300	61.4	0.163	1.0	6
300 - 3000			f/300	6
3000 - 15000			10	6
15000 - 300000			10	$616000/f^{1.2}$

Part B
Induced and Contact Radiofrequency Currents#

Frequency Range	Maximum Current (mA)		
	Through both feet	Through each foot	Contact
0.003 - 0.1 MHz	2000f	1000f	1000f
0.1 - 100 MHz	200	100	100

f = frequency in MHz

* The exposure values in terms of electric and magnetic field strengths are the values obtained by spatially averaging values over an area equivalent to the vertical cross-section of the human body.

† The plane-wave equivalent power density values, although not appropriate for near-field conditions,are commonly used for a convenience of comparison with MPEs at higher frequencies and are displayed on some instruments in use.

It should be noted that the current limits given above may not adequately protect against startle reactions and burns caused by transient discharges when contacting an energized object.

Table 2. Maximum Permissible Exposure for Uncontrolled Environments [8].

Part A
Electromagnetic Fields*

1 Frequency Range (MHz)	2 Electric Field Strength (E) (V/m)	3 Magnetic Field Strength (H) (A/m)	4 Power Density (S) E-Field, H-Field (mW/cm^2)	5 Averaging Time $\|E\|^2$, S (minutes)	5 Averaging Time or $\|H\|^2$ (minutes)
0.003 - 0.1	614	163	(100, 1000000)†	6	6
0.1 - 1.34	614	16.3/f	(100, $10000/f^2$)†	6	6
1.34 - 3.0	823.8/f	16.3/f	($180/f^2$, $10000/f^2$)†	$f^2/0.3$	6
3.0 - 30	823.8/f	16.3/f	($180/f^2$, $10000/f^2$)†	30	6
30 - 100	27.5	$158.3/f^{1.668}$	(0.2, $940000/f^{8.336}$)	30	$0.0636f^{1.337}$
100 - 300	27.5	0.0729	1.2	30	30
300 - 3000			f/1500	30	
3000 - 15000			f/1500	90000/f	
15000 - 300000			10	$616000/f^{1.2}$	

Part B
Induced and Contact Radiofrequency Currents#

Frequency Range	Maximum Current (mA)		
	Through both feet	Through each foot	Contact
0.003 - 0.1 MHz	900f	450f	450f
0.1 - 100 MHz	90	45	45

f = frequency in MHz

* The exposure values in terms of electric and magnetic field strengths are the values obtained by spatially averaging values over an area equivalent to the vertical cross-section of the human body.

† The plane-wave equivalent power density values, although not appropriate for near-field conditions,are commonly used for convenienc of comparison with MPEs at higher frequencies and are displayed on some instruments in use.

\# It should be noted that the current limits given above may not adequately protect against startle reactions and burns caused by transient discharges when contacting an energized object.

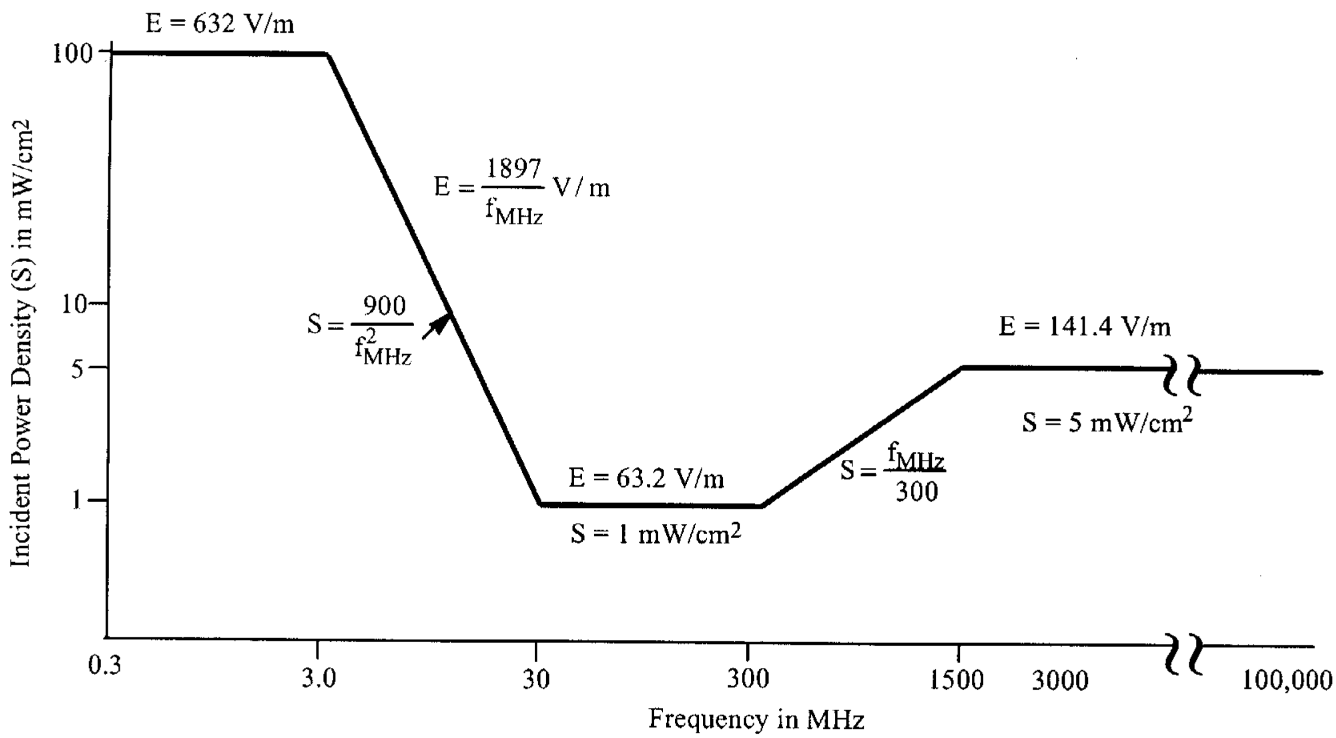

Fig. 1. The ANSI C95.1-1982 Safety Guideline for human exposure to RF electromagnetic fields [1].