

American National Standard

safety levels with respect to
human exposure to radio frequency
electromagnetic fields, 300 kHz to 100 GHz

ANSI C95.1-1982



american national standards institute, inc

September 1, 1982

SH08631

7

American National Standard Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 300 kHz to 100 GHz

1. Scope and Purpose

Recommendations are made to prevent possible harmful effects in human beings exposed to electromagnetic fields in the frequency range from 300 kHz to 100 GHz. These recommendations are intended to apply to non-occupational as well as to occupational exposures. These recommendations are not intended to apply to the purposeful exposure of patients by or under the direction of practitioners of the healing arts.

2. Definitions

radio frequency protection guides (RFPG). The radio frequency field strengths or equivalent plane wave power densities which should not be exceeded without (1) careful consideration of the reasons for doing so, (2) careful estimation of the increased energy deposition in the human body, and (3) careful consideration of the increased risk of unwanted biological effects.

specific absorption rate (SAR). The time rate at which radio-frequency electromagnetic energy is imparted to an element of mass of a biological body.

3. References

- [1] BARBER, P. W. Electromagnetic Power Absorption in Prolate Spheroidal Models of Man and Animals. *IEEE Transactions on Bio-medical Engineering*, 24, 1977, pp 513–521.
- [2] BAWIN, S. M., KACZMAREK, L. K. and ADEY, W. R. Effects of Modulated VHF Fields on the Central Nervous System. *Annals of the New York Academy of Sciences*, 247, 1975, pp 74–81.
- [3] BENER. Nonionizing Electromagnetic Radiation (0–300 GHz). Prepared for the National Telecommunications and Information Administration by the Interagency Task Force on Biological Effects of Nonionizing Electromagnetic Radiation, Oct, 1979.
- [4] BERMAN, E., KINN, J. B. and CARTER, H. B. Observations of Mouse Fetuses after Irradiation With 2.45 GHz Microwaves. *Health Physics*, 35, 1978, pp 791–801.
- [5] BLACKMAN, C. F., ELDER, J. A., WEIL, C. M., BENANE, S. G., EICHINGER, D. C. and HOUSE, D. E. Induction of Calcium-Ion Efflux from Brain Tissue by Radio-Frequency Radiation: Effects of Modulation Frequency and Field Strength. *Radio Science*, 14/6S, 1979, pp 93–98.
- [6] CHATTERJEE, I., GANDHI, O. P., HAGMANN, M. J. and RIAZI, A. A Method of Calculating Electromagnetic Absorption under Near-Field Exposure Conditions. *Abstracts, 1979 Bioelectromagnetics Symposium*. National Academy of Sciences, Washington, DC, 1979, p 350.
- [7] CHATTERJEE, I., HAGMANN, M. J. and GANDHI, O. P. Electromagnetic Energy Deposition in an Inhomogeneous Block Model of Man for Near-Field Irradiation Conditions. *Digest of Technical Papers, 1980 IEEE-MTT*

Society International Microwave Symposium. IEEE: New York, NY, 1980, pp 337–340.

[8] CONOVER, D. L., MURRAY, W. E., FOLEY, E. D., LARY, J. M. and PARR, W. H. Measurement of Electric and Magnetic Field Strengths from Industrial Radio Frequency (6–38 MHz) Plastic Sealers. *Proceedings of the IEEE*, 68, 1980, pp 17–20.

[9] D'ANDREA, J. A., GANDHI, O. P., LORDS, J. L., DURNEY, C. H., JOHNSON, C. C. and ASTLE, L. Physiological and Behavioral Effects of Chronic Exposure to 2450 MHz Microwaves. *Journal of Microwave Power*, 14, 1979, pp 351–362.

[10] DURNEY, C. H. Electromagnetic Dosimetry for Models of Humans and Animals: A Review of Theoretical and Numerical Techniques. *Proceedings of the IEEE*, 68, 1980, pp 33–40.

[11] DURNEY, C. H., JOHNSON, C. C., BARBER, P. W., MASSOUDI, H., ISKANDER, M. F., LORDS, J. L., RYSER, D. K., ALLEN, S. J. and MITCHELL, J. C. *Radiofrequency Radiation Dosimetry Handbook*, Second Edition, May 1978, Report SAM-TR-78-22, USAF School of Aerospace Medicine: Brooks Air Force Base, Texas.

[12] FREY, A. H., FELD, S. R. and FREY, B. Neural Function and Behavior: Defining the Relationship. *Annals of the New York Academy of Sciences*, 247, 1975, pp 433–439.

[13] GANDHI, O. P. Conditions of Strongest Electromagnetic Power Deposition in Man and Animals. *IEEE Transactions on Microwave Theory and Techniques*, 23(12), 1975, pp 1021–1029.

[14] GANDHI, O. P., SEDIGH, K., BECK, G. S. and HUNT, E. L. Distribution of Electromagnetic Energy Deposition in Models of Man with Frequencies near Resonance. *Biological Effects of Electromagnetic Waves*, Johnson, C. C. and Shore, M. L. (Eds), DHEW Publications (FDA) 77-8011, vol 2, 1976, pp 44–67.

[15] D'ANDREA, J. A., GANDHI, O. P. and LORDS, J. L. Behavioral and Thermal Effects of Microwave Radiation at Resonant and Non-Resonant Wavelengths. *Radio Science*, 12(6s), 1977, pp 251–256.

[16] GLASER, Z. R., BROWN, P. F., ALLAMONG, J. M. and NEWTON, R. NIOSH Technical Report, DHEW (NIOSH) Pub no 78–126, Ninth Supplement to Bibliography of Reported Biological Phenomena (“Effects”) and Clinical Manifestations Attributed to Microwave and Radiofrequency Radiation, 1977. (References to previous supplements and an original bibliography dating to 1971 are contained in the Ninth Supplement.)

[17] GLASER, Z. R., CLEVELAND, R. F. and KIELMAN, J. K. *Bioeffects*, Chapter 3, NIOSH Draft Criteria Document on Radiofrequency and Microwave Radiation. National Institute for Occupational Safety and Health, Washington, DC [Director's Draft], 1979, pp 29–330.

[18] GUY, A. W. Quantitation of Induced Electromagnetic Field Patterns in Tissue, and Associated Biological Effects. *Biologic Effects and Health Hazards of Microwave Radiation* (Czerski, P., Ed), Polish Medical Publishers, Warsaw, 1974, pp 203–216.

[19] GUY, A. W., KRAMAR, P. O., HARRIS, C. A. and CHOU, C. K. Long-Term 2450 MHz CW Microwave Irradiation of Rabbits: Methodology and Evaluation of Ocular and Physiological Effects. *Journal of Microwave Power*, 15, 1980, pp 37–44.

[20] GUY, A. W., WEBB, M. D. and SORESEN, C. C. Determination of Power Absorption in Man Exposed to High-Frequency Electromagnetic Fields by Thermographic Measurements on Scale Models. *IEEE Transactions on Biomedical Engineering*, 23, 1976, pp 361–371.

[21] JUSTESEN, D. R. Behavioral and Psychological Effects of Microwave Radiation. *Bulletin of the New York Academy of Medicine*, 55, 1980, pp 1058–1078.

[22] JUSTESEN, D. R. Microwave Irradiation and the Blood-Brain Barrier. *Proceedings of the IEEE*, 68, 1980, pp 60–67.

[23] JUSTESEN, D. R. Toward a Prescriptive Grammar for the Radiobiology of Non-Ionising Radiations: Quantities, Definitions, and Units of Absorbed Electromagnetic Energy. *Journal of Microwave Power*, 10, 1975, pp 333–356.

[24] JUSTESEN, D. R. and KING, N. W. Behavioral Effects of Low-Level Microwave

Irradiation in the Closed-Space Situation. *Symposium Proceedings: Biological Effects and Health Implications of Microwave Radiation*, no BRH/DBE 70-2, Cleary, S. F., Ed (USPHS-FDA, Rockville, MD), 1970, pp 154–179.

[25] JUSTESEN, D. R., RAGAN, H. A., ROGERS, L. E., GUY, A. W., HJERESEN, D. L., HINDS, W. T. and PHILLIPS, R. D. *Compilation and Assessment of Microwave Bioeffects: A Selective Review of the Literature on Biological Effects of Microwaves in Relation to the Satellite Power System*, no PNL-2634 (Revision). Department of Energy, Washington, DC, 1978.

[26] LOVELY, R. H., GUY, A. W., JOHNSON, R. B. and MATHEWS, M. Alteration of Behavior and of Biochemical Parameters During and Consequent to 500 $\mu\text{W}/\text{cm}^2$ Chronic 2450 MHz Microwave Exposure. *Abstracts of Scientific Papers, 1978 Symposium on Electromagnetic Fields in Biological Systems*. International Microwave Power Institute, Edmonton, Alberta, 1978, p 34.

[27] MC REE, D. I. A Technical Review of the Biological Effects of Non-Ionizing Radiation. Office of Science and Technology Policy, Washington, DC, 1978.

[28] MILD, K. H. Occupational Exposure to Radio Frequency Electromagnetic Fields. *Proceedings of the IEEE*, 68, 1980, pp 12–17.

[29] MUMFORD, W. W. Heat Stress Due to RF Radiation, *Proceedings of the IEEE*, 57, 1969, pp 171–178.

[30] NCRP, Radiofrequency Electromagnetic Fields: Properties, Quantities and Units, Biophysical Interaction and Measurement. Pub no 67, National Council on Radiation Protection and Measurements, Washington, DC, 1981.

[31] O'CONNOR (Chernovetz), M. E., JUSTESEN, D. R., KING, N. W. and WAGNER, J. E. Teratology, Survival, and Reversal Learning after Fetal Irradiation of Mice by 2450 MHz Microwave Energy. *Journal of Microwave Power*, 10, 1975, pp 391–409.

[32] O'CONNOR (Chernovetz), M. E., JUSTESEN, D. R. and LEVINSON, D. M. Acceleration and Deceleration of Fetal Growth of Rats by 2450 MHz Irradiation. *Proceedings of the 1978 Symposium on Electromagnetic Fields in Biological Systems* (Stuchly, S., Ed). Inter-

national Microwave Power Institute, Edmonton, Alberta, 1979, pp 175–193.

[33] O'CONNOR (Chernovetz), M. E., JUSTESEN, D. R. and OKE, A. F. A Teratological Study of the Rat: Microwave and Infrared Radiations Compared. *Radio Science*, 12(6S), 1977, pp 191–197.

[34] RUCH, T. G. and PATTON, H. C., (Eds). *Physiology and Biophysics*. W. B. Saunders, Philadelphia, Pennsylvania, 1973.

[35] RUGH, R., GINNS, E. I., HO, H. S. and LEACH, W. M. Are Microwaves Teratogenic? *Biologic Effects and Health Hazards of Microwave Radiation*. (Czerski, P., Ed). Polish Medical Publishers, Warsaw, 1974, pp 98–108.

[36] RUGH, R., GINNS, E. I., HO, H. S. and LEACH, W. M. Response of the Mouse to Microwave Radiation during Estrous Cycle and Pregnancy. *Radiation Research*, 62, 1975, pp 225–241.

[37] RUGH, R. and MC MANAWAY, M. Are Mouse Fetuses Uniformly Sensitive to Microwave Radiation? *Teratology*, 13, 1976, pp 34A–35A.

[38] TELL, R. A. and HARLEN, F. A Review of Selected Biological Effects and Dosimetric Data Useful for Development of Radiofrequency Safety Standard for Human Exposure. *Journal of Microwave Power*, 14, 1979, pp 405–424.

[39] ANSI C95.3-1973 (R1979), American National Standard Techniques and Instrumentation for the Measurement of Potentially Hazardous Electromagnetic Radiation at Microwave Frequencies.

[40] LICHT, S. *Therapeutic Heat*. (E. Licht, pub), New York, 1965.

[41] JORDAN, E. C. *Electromagnetic Waves and Radiating Systems*. Prentice Hall, 1950, p 323.

4. Recommendations

4.1 Radio Frequency Protection Guides. For human exposure to electromagnetic energy at radio frequencies from 300 kHz to 100 GHz, the protection guides, in terms of the mean squared electric (E^2) and magnetic (H^2)

Table 1
Radio Frequency Protection Guides

1	2	3	4
Frequency Range (MHz)	E^2 (V^2/m^2)	H^2 (A^2/m^2)	Power Density (mW/cm^2)
0.3 — 3	400 000	2.5	100
3 — 30	4000 ($900/f^2$)	0.025 ($900/f^2$)	$900/f^2$
30 — 300	4000	0.025	1.0
300 — 1500	4000 ($f/300$)	0.025 ($f/300$)	$f/300$
1500 — 100 000	20 000	0.125	5.0

Note: f = frequency (MHz).

field strengths and in terms of the equivalent plane-wave free-space power density, as a function of frequency, are given in Table 1.

For near field exposures, the only applicable protection guides are the mean squared electric and magnetic field strengths as given in Table 1, columns 2 and 3. For convenience, these guides may be expressed as the equivalent plane wave power density, given in Table 1, column 4.

For mixed or broadband fields at a number of frequencies for which there are different values of protection guides, the fraction of the radio frequency protection guide incurred within each frequency interval should be determined, and the sum of all such fractions should not exceed unity.

4.2 Exclusions

(1) At frequencies between 300 kHz and 100 GHz, the protection guides may be exceeded if the exposure conditions can be shown by laboratory procedures to produce specific absorption rates (SARs) below 0.4 W/kg as averaged over the whole body, and spatial peak SAR values below 8 W/kg as averaged over any one gram of tissue.

(2) At frequencies between 300 kHz and 1 GHz, the protection guides may be exceeded if the radio frequency input power of the radiating device is seven watts or less.

4.3 Measurements

(1) For both pulsed and non-pulsed fields, the power density, the squares of the field strengths, and the values of specific absorption rates (SARs) or input power, as applicable, are averaged over any 0.1 h period. The time-averaged values should not exceed the values given in Table 1 or in the Exclusions, 4.2.

(2) Measurements to determine adherence to

the recommended protection guides shall be made at distances 5 cm or greater from any object (refer to ANSI C95.3-1979 [39]¹).

5. Explanation

Exposure to electromagnetic fields in the frequency range under consideration is but one of the several sources of energy input into the body, which requires wide ranges of energy production and dissipation in order to function. For situations involving unrestricted exposure of the body, the radio frequency protection guides are believed to result in energy deposition averaged over the entire body mass for any 0.1 h period of about 144 joules per kilogram (J/kg) or less. This is equivalent to a specific absorption rate (SAR) of about 0.40 watts per kilogram (W/kg) or less, as spatially and temporally averaged over the entire body mass.

Biological effects data applicable to humans for all possible combinations of frequency and modulation do not exist. The radio frequency protection guide, therefore, has been based on the best available interpretations of the literature and is intended to eliminate adverse effects on the functioning of the human body.

Exclusion criterion (2) to the protection guides can be used in relation to fields from low power devices such as hand-held, mobile, and marine radio transceivers. These devices may emit localized fields exceeding the protection guides, but will result in a significantly lower rate of energy absorption than allowed for the whole body average. Thus, exposure to

¹The numbers in brackets correspond to the References listed in Section 3 of this standard.