American National Standard

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

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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 nonoccupational 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.

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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

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

fields emitted by devices operating at 1 GHz or lower and at less than 7 W output power would not be restricted. Exposure to fields from devices with greater output power or operating at frequencies above 1 GHz require a case-by-case analysis to determine if exclusion criterion (1) is applicable.

Because of the limitations of the biological effects data base, these guides are offered as upper limits of exposure, particularly for the population at large. Where exposure conditions are not precisely known or controlled, exposure reduction should be accomplished by reliable means to values as low as are reasonably achievable. Exposures slightly in excess of the radio frequency protection guides are not necessarily harmful, however, such exposures are *not* desirable and should be prevented wherever possible.

6. Rationale

American National Standards Institute (ANSI) policy requires that each of its standards or guides shall be reviewed at five year intervals. At the time of expiration, the standard or guide may be retained, revised, or rescinded in accord with the consensus of the reviewing body. In 1974, the members of the reviewing body, ANSI Subcommittee C95-IV, retained most of the provisions of the previous guide, but qualified the recommended exposure limits on power densities by specifying limits on strengths of both field components (electrical and magnetic) of radio-frequency electromagnetic (rfem) fields.

During 1978, 1979, and 1980, members of Subcommittee C95-IV met on several occasions to discuss the 1974 guide and to review data and developments that had been forthcoming since its publication. From these discussions and reviews consensus was reached on a number of issues and concerns. First, no verified reports exist of injury to or adverse effects on the health of human beings who have been exposed to rfem fields within the limits of frequency and power density specified by previous ANSI guides. Second, in spite of the absence of verified reports of injury, the physical and biological data upon which earlier guides have been based are quite limited. Moreover, previous guides were based on the assumption that only gross thermal effects, those borne of elevations of core temperature, are potential causes of biological reactivity. While recognizing the dangers of excessive elevations of temperature [1], the subcommittee also recognized the dangers of prejudgment in light of unsettled questions of field-body mechanisms of interaction and of emerging data that indicate the existence of athermal effects [3], [17], [25], [27]. Third, the subcommittee recognized that previous ANSI guides have been interpreted widely as occupational standards, applicable only to settings where the health status of exposed personnel is known and the working environment is under control of the operator of a source of rfem fields. In view of the rapidly expanding use of private and public sources such as citizen's band radio, and mobile and marine transmitters, and in recognition that FM and TV broadcasts constitute dominant sources of rfem fields in the environment of the average citizen, the subcommittee recognized the need for a general-population guide. And fourth, the subcommittee recognized that previous ANSI guides have provided the basis for almost all national and industrial standards of human exposure to rfem fields. Accordingly, withdrawal of an ANSI guide was considered highly undesirable. Retention of the 1974 guide was also viewed as undesirable in the light of new data and developments [16]. The decision was made to revise the guide in spite of acknowledged gaps that persist in the existing base of data [17], [22], [27].

The 1982 Radio Frequency Protection Guide (RFPG) is an extension of its 1974 predecessor with several notable refinements.

6.1 Recognition of Whole-Body Resonance. As is true of the 1974 guide, the 1982 RFPG is based on recommendations of maximal permissible limits (MPL) of field strength or of plane-wave-equivalent power densities of incident fields, but these limits are based on now well established findings that the body as a whole exhibits frequency-dependent rates of absorbing rfem energy [1], [10], [11], [13]. Whole-body-averaged absorption rates approach maximal values when the long axis of a body is parallel to the *E*-field vector and is four tenths of a wavelength of the incident field. At 2450 MHz, for example, Standard Man (long axis 175 cm) will absorb about half of the incident rfem energy. At frequencies that result in maximal absorption, which defines whole-body resonance, the electrical cross section of an exposed body increases in area. This increase occurs at a frequency near 70 MHz for Standard Man and results in an approximate sevenfold increase of absorption relative to that in a 2450 MHz field [14], [15]. In consideration of this dependency, recommended MPLs of field strength have been reduced across the range of frequencies in which human bodies from small infants to large adults exhibit whole-body resonance.

6.2 Incorporation of Dosimetry. Dosimetry is the fundamental process of measuring physical quantities of energy or substances that are imparted to an absorbing body [23], [24]. In 1972, The National Council on Radiation Protection and Measurements (NCRP) convened Scientific Committee 39 to deliberate and recommend dosimetric quantities and units applicable to rfem fields [30]. In keeping with the NCRPs recommendations, the ANSI subcommittee adopted the unit-mass, time-averaged rate of rfem energy absorption as specified in SI units of watts per kilogram ($W \cdot kg^{-1}$). The quantity expressed by these units is termed the specific absorption rate (SAR) and depends on a finite period of exposure to yield the amount of energy absorbed by a given mass of material, which is termed specific absorption (SA),[2] that is, Joules per kilogram = $J \cdot kg^{-1} = W \cdot s \cdot kg^{-1}$.

Formally defined, the specific absorption rate is the time rate at which radio-frequency electromagnetic energy is imparted to an element of mass of a biological body.

The SAR is applicable to any tissue or organ of interest (that is, can be applied to any macromolecular element of mass) or, as utilized in the 1982 RFPG, is expressed as a whole-body average. Ideally, anatomical distributions of SARs would be used explicitly in formulating a guide in recognition that absorption of rfem energy from even the most uniform field can result in highly variable anatomical depositions of energy. Guy and his colleagues have established through thermographic analyses of models of rats and man, and cadavers of rabbits, that peaks of the SAR can range more than an order of magnitude above a whole-body average [18], [19], [20]. Comparable findings have been reported by Gandhi [14]. However, several factors preclude explicit use of peak SARs: (1) the availability of data on distributive SARs is limited, and (2) SAR distributions are highly variable since they are dependent on wavelength, polarization, and zone of the incident field, and on the mass and momentary geometry of the biological body. The number of the complex family of SAR distributions approaches infinity. It is recognized, however, that a whole-body-averaged SAR is the mean of a distribution, the high side of which is an envelope of electrical hotspots. These localized SARs range from mean to peak and when integrated with localized SARs of less than the mean value, equal the whole-body average. Moreover, for any given orientation of a given species in a given field, the *correlation* between the magnitude of a whole-body-averaged SAR and that of any lower or higher part-body SAR must approach unity, that is, if the power density of an incident rfem field is increased, the relative increase of the whole-body SAR will be directly proportional to the increase of any part-body SAR. Because of the invariable presence of electrical hotspots in the irradiated body and the inherent correlation between magnitudes of whole-body and part-body SARs, a biological effect induced by a localized SAR that is well above the whole-body average will be reflected to some extent by that average. The predictive utility of the correlation between part and whole has long served clinical and experimental medicine in which a whole-body, unit-mass dosimetry underlies therapeutic administration of pharmacological agents.

6.3 Expanded Data Base. The data base from which the 1982 RFPG was developed is considerably broader than that of the 1974 guide [16], [17]. After several hundred reports in the biomedical literature on rfem fields were reviewed by members of working groups of ANSI Subcommittee C95-IV, a select list of experimental reports was compiled in accord

[2] Some authors have used the terms *dose rate* ($\dot{D}$) and *dose* (D) instead of, respectively, *specific absorption rate* and *specific absorption*. The rfem-energy dose rate and the SAR are identical in meaning and definition (as are D and SA). Absorbed power density, when expressed as a volume integral, has also been used as a synonym for the SAR. The SAR is used exclusively in the 1982 RFPG to prevent confusion with dosimetric terminology used in the study and application of ionizing radiations.

with several criteria; they are: demonstrability (that is, positive data), relevance, reproduceability, and dosimetric quantifiability. The reports in the select list (see Table A1, Appendix) cover a wide range of external and internal field strengths associated with positive findings but are not representative of the data base because of the bias toward positive findings. This bias is justified on two grounds: (1) while negative findings are useful in evaluating the generality of data, they cannot displace the positive findings upon which a rational standard must be based, and (2) selection of positive findings injects a degree of worst-case conservatism into the guide and therefore constitutes an additional factor of safety. In compiling the select list of reports, the members of the subcommittee often screened several studies from different laboratories that had yielded positive findings of relevance to a common end point. For example, data from teratological studies of microwave irradiation have been reported in many papers by Roberts Rugh and his associates [35], [36], [37] and by M. E. O'Connor and her associates [31], [32], [33] yet only the report by Berman was chosen for inclusion [4]. This choice was made because positive findings were claimed at much lower field strengths than those employed by other investigators and because the periods of exposing animals are among the longest of any reported in the literature on microwave teratology.

6.4 Broadened Assessment Criteria. In assessing positive reports of biological effects, the subcommittee emphasized studies that had generated evidence of morbidity or debilitation, chronic or acute. The most sensitive measures of biological effects were found to be based on behavior [9], [12], [15], [21], [25], [26]. Because of the paucity of reliable data on chronic exposures, the subcommittee focused on evidence of behavioral disruption under acute exposures, even that of a transient and fully reversible character. The assumption is that reversible disruption during an acute exposure is tantamount to irreversible injury during chronic exposure. The whole-body-averaged SARs associated with thresholds of reversible behavioral disruption were found to range narrowly between 4 and 8 W/kg in spite of considerable differences in carrier frequency (600 MHz to 2.45 GHz), species (rodents versus primates), and mode of irradiation (cavity, waveguide, and plane wave). In contrast, the time-averaged power densities of incident radiation associated with these thresholds of disruption ranged (by calculation or measurement) from 10 to 50 mW/cm^2. During the assessment procedure, classification and judgment of findings were made without prejudgment of mechanisms of effects. The subcommittee's intent was that of protecting exposed human beings from harm by *any* mechanism, including those arising from excessive elevations of body temperature.

6.5 Two-Tier Assessment. After the select list of reports was compiled, each report was evaluated on a case by case basis by the subcommittee's biologically trained scientists. The subcommittee's physical and biological scientists then evaluated the reports in terms of reliability and evidence of adverse effects. The discussion focused on thresholds of adverse effects, the extent to which findings had been verified in independent investigations, and roles played by confounding factors. There was general agreement that adverse effects of acute exposures are associated with whole-body specific absorption rates (SAR) above 5 W/kg. On the other hand, whole-body SARs below 4 W/kg were not by consensus associated with effects that demonstrably constitute a hazard. Some effects reported in the Eastern European literature were discounted because of questionable control procedures and lack of information on environmental parameters and physical measurements. In addition, modulation-specific effects, such as efflux of calcium ions from brain materials [2], [5] were not considered adverse because of the inability of the subcommittee's members to relate them to human health. The narrow ranges of power density and the low and narrow range of modulation frequencies associated with field-induced efflux of calcium ions, and the authors' findings that the phenomenon is reversible, are factors that entered into the subcommittee's deliberations. The consensus remained that reliable evidence of hazardous effects is associated with whole-body-averaged SARs above 4 W/kg.

6.6 Safety Factor. To ensure a wide margin of safety, an order-of-magnitude reduction in the permissible whole-body-averaged specific absorption rate (SAR) to 0.4 W/kg was invoked.

This decision was nearly unanimous; one biological scientist dissented on the grounds that a specific justification should be given for the power-of-ten reduction. Different biological scientists offered different reasons, but beyond the need for a wide margin of safety, no quantitative justification was advanced. None of the members of the subcommittee offered an argument to widen the margin of safety.

It is noted in Fig A3 (see Appendix) that the majority of case reports are in the range of microwave frequencies; most of these reports are based on a frequency at or near 2450 MHz. This narrow data base of frequencies sheds little light on the relative biological effectiveness of rfem radiation as a function of frequency. However, no verified theory that would predict frequency specificity because of possible athermal effects has been advanced. In the absence of any contrary experimental or theoretical evidence the subcommittee assumed no wavelength dependencies beyond those of depth of penetration and whole-body resonance. Given these assumptions, the physical scientists of the subcommittee were asked to determine frequency-dependent limits of exposure. The results of theoretical calculations and experimental modeling of absorbed energy for various conditions of human exposure as reported by several authors are shown in Fig A2 of the Appendix (see legend to Fig A2).

The SAR envelope for plane-wave exposures at 1 mW/cm^2 as a function of frequency was determined for human beings from small infant to large adult (see curve 16, Fig A2). The maximal permissible limit (MPL) was determined from 300 kHz to 100 GHz. The results are shown in Fig A1 of the Appendix. Above 1.5 GHz the curve is assumed to be flat. It should be noted that curve 16, Fig A2, is not extended above 1 GHz, but the general trend of flattening with frequency is indicated by all other curves of Fig A2. As frequency decreased below 30 MHz, the quantity of rfem energy absorbed by human beings of any size decreases substantially. Nonetheless, it was recommended that field strengths at frequencies below 3 MHz be limited to those associated with a plane-wave-equivalent power density of 100 mW/cm^2. This limit is intended to prevent reactions at the body's surface that can occur in E fields of high intensity.

The limiting rate of energy absorption of 0.4 W/kg is predicated on a biological body that is located in a linearly polarized plane-wave field, that is, the case in which the long axis of the body is parallel to the vector of the E field. This case presumes near-maximal absorption of rfem energy. By adopting the principle of maximal coupling, the subcommittee intended to introduce yet another element of conservatism into the guide.

6.7 Near-Field Exposures. The subcommittee recognized that the assumption of a plane-wave exposure is simplistic and is not a realistic approximation of most exposures that pose a risk to health; such exposures occur in relative close proximity to rfem sources in the near field [8], [28]. Fortunately, because of the highly localized nature of the fields in the near zone, the whole-body-averaged SARs associated with them will be below those induced by plane waves of equivalent field strengths.

6.8 Other Factors. It was recognized by the subcommittee that the specific absorption rate (SAR), which provides the basis for limiting power densities, does not contain all of the factors that could be of importance in establishing safe limits of exposure. First, other characteristics of an incident field such as modulation frequency and peak intensity may pose a risk to health. Again, the data base does not provide the evidence of adversity by which to recommend special provisions for modulated fields. There was an *intuitive* concern by some members of the subcommittee that caution should be exercised when individuals are exposed to a pulse-modulated field of high peak but low averaged density, or to a sinusoidally-modulated field, when either field has a recurrence rate in the range of bioelectric rhythms. A supportable way of expressing this concern, which would be applicable to all exposed populations, could not be reached.

A considerable degree of conservatism has been incorporated in the RFPG to make it applicable to the control of non-occupational as well as to occupational exposures. Accordingly, the need for special considerations of environmental conditions such as extremes of temperature and humidity is averted. Previous guides have recommended reduction of maximum permissible limits (MPLs) of power density in hot, humid environments in recognition of the potential thermal burden imposed thereunder by 10 mW/cm^2 fields [29]. This

RFPG effectively controls the thermally adverse environment by limiting the permissible rate of energy absorption to a level that precludes excessive elevations of body temperature [38].

Some of the members of the subcommittee expressed a concern for toxic chemical agents that might be present in the environment and might, in combination with exposure to rfem fields, constitute a hazard. However, the absence of evidence that toxic agents are potentiated by weak rfem fields led the subcommittee to concur that the 1982 RFPG is sufficiently conservative to make additional precautions unnecessary and, particularly in view of the difficulty of administering such precautions effectively, to advise against their inclusion as an adjunct to the RFPG.

6.9 Restriction on Measurement. The subcommittee recognized that objects immersed in an electromagnetic field at strengths below those specified in Table 1 of the RFPG can produce a scattered field of apparent intensity greatly exceeding that of a primary source. The apparent strength of a scattered field can be enhanced by many orders of magnitude in close proximity to an object and is an inverse function of distance from the object. The apparent strength is also dependent on the geometry of the object. Valid measurement of scattered fields is difficult due to the finite size of the field sensor and to its interaction with the object. It is also recognized that the quantity of energy that can be coupled from a scattered field to a large body (that is, that of a human being) is small compared with that from the primary source. Thus, based on fundamental considerations of scattering properties of absorbing or reflecting objects in an rfem field and on consideration of the practical limitations of measuring instruments, it was agreed that measurements of field strengths to determine adherence to the RFPG are to be made at distances 5 cm or greater from any object.

6.10 Special Exclusion. The subcommittee recognized that many low-power devices that are used by a large segment of the general population, such as citizen's band radio, and amateur, public-safety, land-mobile and marine transmitters, may generate localized fields that appear to exceed the RFPG but result in a significantly lower rate of whole-body-averaged energy absorption as a result of the limited area of exposed tissue. For example, calculation of field strengths and localized power densities in proximity to an ideal 150 MHz quarter-wave antenna mounted on a ground plane with an input power of two watts (Table A2, Appendix) reveal that human exposure at a distance 20 cm or less from the antenna would be prohibited by the RFPG even though the highest possible rate of energy absorption is less than seven percent of that allowed for a whole-body exposure to a plane wave.

6.11 Exclusion. The subcommittee agreed that the only practical way to cope with the problem of low-power devices was to enter an exclusion clause in the RFPG that would allow the power density (and local strengths) of incident fields to be exceeded under certain conditions. The exclusion is based on the following considerations:

(1) It would not violate the general provisions of the RFPG. The whole-body-averaged rate of energy absorption during localized exposure should be less than 0.4 W/kg, and anatomically localized rates should not exceed those that are expected from a whole-body exposure to a plane wave that results in an average specific absorption rate (SAR) of 0.4 W/kg. By implication and demonstration, peak SARs in a biological body can range more than an order of magnitude above the average SAR over a limited mass of the exposed tissue.

(2) It would be unlikely for devices such as low-power hand-held radios operating at frequencies below 1 GHz and radiating at rfem power levels below 7 W to couple enough energy into any size human body to violate the general provisions of the RFPG.

Therefore, the subcommittee included in the standard a provision for the exclusion of a particular source from the general RFPG, provided it could be competently shown that for any individual that might be exposed to emissions from that source the whole-body-averaged SAR would not exceed 0.4 W/kg and that any spatial peak value of the SAR would not exceed 8 W/kg as averaged over any one gram of tissue and over any time period of 0.1 h.

It was also recognized by the subcommittee that to determine whether a particular rf source would meet these absorption criteria would be difficult and could be done only by a properly qualified laboratory or by an appropriate scientific body for a general class of equipment. In no case could a routine field survey determine conformance with the criteria of this part of the exclusion.

The subcommittee further recognized that it would be unnecessary to validate the dosimetry criteria for the application of the exclusion clause if the maximal input power of the radiating device is seven watts or less. The seven watts that is allowable under the exclusion clause is, by way of comparison, more than an order of magnitude below power levels of equipment that is routinely used in the clinic for part-body treatment by diathermy [40]. Furthermore, it is difficult to envision any operating conditions where more than a small fraction of the rfem energy from a 7 W device could be absorbed by a human body. The 7 W exclusion should be limited to frequencies below 1 GHz to prevent known, adverse biological consequences of exposure to intense collimated beams.

6.12 Time Averaging. The subcommittee retained 0.1 h (6 min) as the significant period of time over which exposures, the values of specific absorption rates (SAR) and input power are to be averaged.

Appendix

(This Appendix is not a part of ANSI C95.1-1982, American National Standard Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 300 kHz to 100 GHz.)

List of Selected Reports Biological Effects of RFEM Fields[3]

A1. Environmental Factors

JOHNSON, R. B., MIZUMORI, S., LOVELY, R. H., and GUY, A. W. Adaptations to Microwave Exposure as a Function of Power Density and Ambient Temperature in the Rat. *Abstracts, 1978 Symposium on Electromagnetic Fields in Biological Systems.* International Microwave Power Institute, Edmonton, Alberta, 1978, p 30.

MONAHAN, J. C. and HO, H. S. The Effect of Ambient Temperature on the Reduction of Microwave Energy Absorption by Mice. *Radio Science*, 12(6S), 1977, pp 257—262.

SHANDALA, M. G., RUDNEV, M. I. and NAVAKATIAN, M. A. Patterns of Change in Behavioral Reactions to Low Power Densities of Microwaves. *Abstracts, 1977 International USNC/URSI Symposium on the Biological Effects of Electromagnetic Waves.* National Academy of Sciences, Washington, DC, 1977, p 88.

A2. Behavior

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.

FREY, A. H. Behavioral Effects of Electromagnetic Energy. *Biological Effects and Measurement of Radio Frequency/Microwaves*, D. H. Hazzard (Ed.), HEW Publication (FDA) 77-8026. U.S. Government Printing Office, Washington, DC, 1977, pp 11—22.

FREY, A. H., FELD, S. R. and FREY, B. Neural Function and Behavior: Defining the Relationship. *Annals of the N.Y. Academy of Sciences*, 247, 1975, pp 433—438.

KING, N. W., JUSTESEN, D. R. and CLARKE, R. L. Behavioral Sensitivity to Microwave Irradiation. *Science*, 172, 1971, pp 398—401.

LIN, J. C., GUY, A. W. and CALDWELL, L. R. Thermographic and Behavioral Studies of Rats in the Near Field of 918 MHz Radiation. *IEEE Transactions on Microwave Theory and Techniques*, MTT-25, 1977, pp 833—836.

THOMAS, J. R., FINCH, E. D., FULK, D. W. and BURCH, L. S. Effects of Low-Level Microwave Radiation on Behavioral Baselines. *Annals of the N.Y. Academy of Sciences*, 247, 1975, pp 425—431.

A3. Immunology

CZERSKI, P. Microwave Effects on the Blood-Forming System With Particular Reference to the Lymphocyte. *Annals of the N.Y. Academy of Sciences*, 247, 1975, pp 232—241.

HUANG, A. T., ENGLE, M. E., ELDER, J. A., KINN, J. B. and WARD, T. R. The Effects of Microwave Radiation (2450 MHz) on the Morphology and Chromosomes of Lymphocytes. *Radio Science*, 12(6S), 1977, pp 173—177.

SHANDALA, M. G., RUDNEV, M. I., VINOGRADOV, G. K., BOLONOZHIKO, H. G. and GONCHAR, N. M. Immunological and Hematological Effects of Microwaves at Low Power Densities. *Abstracts, 1977 USNC/URSI International Symposium on the Biological Effects of Electromagnetic Waves*, National Academy of Sciences: Washington, DC, 1977, p 85.

SMIALOWICZ, R. J., KINN, J. E. and ELDER, J. A. Exposure of Rats *In Utero* Through Early Life to 2450 MHz (CW) Microwave Radiation: Effects on Lymphocytes. *Radio Science*, 14(6S), 1979, pp 147—154.

[3] A number of preprints, either published as abstracts or available as editorially accepted manuscripts, were used in preparation of the select list. In each case where a report has been published in an archival journal, reference is to the published paper.

A4. Teratology

BERMAN, E., KIN, J. B. and CARTER, H. B. Observations of Mouse Fetuses After Irradiation with 2.45 GHz Microwaves. *Health Physics*, 35, 1978, pp 791—801.

A5. Central Nervous System/Blood-Brain-Barrier

ALBERT, E. N. Light and Electron Microscope Observations on the Blood-Brain Barrier after Microwave Irradiation. *Biological Effects and Measurements of Radio Frequency/Microwaves*, Hazzard, D. G. (Ed), HEW Publication (FDA) 77-8026 U.S. Government Printing Office, Washington, DC, 1977, pp 294—304.

BAWIN, S. M., KACZMAREK, L. K. and ADEY, W. R. Effects of Modulated VHF Fields on the Central Nervous System. *Annals of the N.Y. Academy of Sciences*, 247, 1975, pp 74—81.

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.

FREY, A. H., FELD, S. R. and FREY, B. Neural Function and Behavior: Defining the Relationship. *Annals of the N.Y. Academy of Sciences*, 247, 1975, pp 433—438.

A6. Cataracts: None ≤ 10 mW/cm^2

A7. Genetics: None ≤ 10 mW/cm^2

A8. Human Studies: None

A9. Thermoregulation and Metabolism

ADAIR, E. R. and ADAMS, B. W. Microwaves Modify Thermoregulatory Behavior in Squirrel Monkeys. *Bioelectromagnetics*, 1, 1980, pp 1—20.

DE LORGE, J. W. Operant Behavior and Colonic Temperature of Squirrel Monkeys During 2450 MHz Microwave Irradiation. *Radio Science*, 14(6S), 1979, pp 217—226.

LOVELY, R. H., MYERS, D. E. and GUY, A. W. Irradiation of Rats by 918 MHz Microwaves at 2.5 mW/cm^2: Delineating the Dose-Response Relationship. *Radio Science*, 12(6S), 1977, pp 139—146.

LU, S. and T., LEBDA, N., MICHAELSON, S. M., PETTIT, S. and RIVERA, D. Thermal and Endocrinological Effects of Protracted Irradiation of Rats by 2450 MHz Microwaves. *Radio Science*, 12(6S), 1977, pp 147—156.

STERN, S., MARGOLIN, L., WEISS, B., LU, S. and T. and MICHAELSON, S. M. Microwaves: Effect on Thermoregulatory Behavior in Rats. *Science*, 206, 1979, pp 1198—1201.

A10. Biorhythms

LU, S. and T., LEBDA, N., MICHAELSON, S. M., PETTIT, S. and RIVERA, D. Thermal and Endocrinological Effects of Protracted Irradiation of Rats by 2450 MHz Microwaves. *Radio Science*, 12(6S), 1977, pp 147—156.

A11. Endocrinology

LOVELY, R. H., Guy, A. W., JOHNSON, R. B. and MATHEWS, M. Alterations of Behavioral and Biochemical Parameters During and Consequent to 500 μW/cm^2 Chronic 2450 MHz Microwave Exposure. *Abstracts, 1978 Symposium on Electromagnetic Fields in Biological Systems*, International Microwave Power Institute: Edmonton, Alberta, 1978, p 34.

LU, S. and T., LEBDA, N., MICHAELSON, S. M., PETTIT, S. and RIVERA, D. Thermal and Endocrinological Effects of Protracted Irradiation of Rats by 2450 MHz Microwaves. *Radio Science*, 12(6S), 1977, pp 147—156.

TRAVERS, W. D. Low Intensity Microwave Effects on the Synthesis of Thyroid Hormones and Serum Proteins, *Health Physics*, 33, 1978, p 662.

A12. Development

GUILLET, R. and MICHAELSON, S. M. The Effect of Repeated Microwave Exposure on Neonatal Rats. *Radio Science*, 12(6S), 1977, pp 125—129.

JOHNSON, R.B., MIZUMORI, S. and LOVELY, R. H. Adult Behavioral Deficits in Rats Exposed to 918 MHz Microwaves. *Developmental Toxicology of Energy Related Pollutants*, M. SIKOV and D. MALUM (Eds), 17th Hanford Symposium. Department of Energy, Washington, DC, 1979, pp 281—299.

MC REE, D. I. and HAMRICK, P. E. Exposures of Japanese Quail Embryos to 2.45 GHz Microwave Radiation during Development. *Radiation Research*, 71, 1977, pp 355—366.

A13. RF Hearing: None

A14. Hematology

MIRO, L., LUBIERE, R. and PFISTER, A. Effects of Microwaves on the Cell Metabolism of the Reticulo-Histiocytic System. *Biologic Effects and Health Hazards of Microwave Radiation*, Czerski, P. (Ed), Polish Medical Publishers, Warsaw, 1974, pp 89—97.

MITCHELL, D. S., SWITZER, W. G. and BRONAUGH, E. L. Hyperactivity and Disruption of Operant Behavior in Rats After Multiple Exposures to Microwave Radiation. *Radio Science*, 12(6S), 1977, pp 263—271.

A15. Cardiovascular

REED, J. R., LORDS, J. L. and DURNEY, C. H. Microwave Irradiation of the Isolated Rat Heart After Treatment with ANS Blocking Agents. *Radio Science*, 12(6S), 1977, pp 161—165.

Table A1
Calculation of Whole-Body SARs for Data in Selected Reports

Research Paper	Reference	Subject and Mass	Orientation to *E* Field	Frequency (GHz)	W/kg per mW/cm²	Modulation	Average Power Density (mW/cm²)	Peak Power Density (mW/cm²)	Duration of Exposure	Average SAR (W/kg)
M. Shandala	A1	Rat (310 g)	Not Specified	2.375	0.21 (medium rat)	CW	0.01 — 0.05	Not Applicable	7 h/day 90 days	0.0021 0.0195
R. Johnson	A1	Rat Embryo (in utero) (445 g)	(Circularly Polarized Field)	0.918	0.30 (large rat)	CW	5	Not Applicable	380 h total	1.5
Monahan and Ho	A1	Mouse (30—34 g)	Waveguide	2.45	SAR Measured Directly	CW	Indeterminate	Not Applicable	20 min	0.6
D'Andrea	A2	Rat (420—450 g)	Long Axis ‖ to E Vector	0.60	0.61	CW	10	Not Applicable	≤ 55 min Repeated, Variable	6.1
Thomas	A2	Rat	Free-moving Animal	2.86 9.6	0.20 — 0.16	1 μs Pulses 500 pps	5	Unknown	1 h	1.0 Far Field 0.8
Frey	A2	Rat (250 g)	Horizontal	1.3	0.36 (medium rat)	0.5 ms Pulses 1000 pps	0.65	1.3 mW/cm²	5 min	Average: 0.23 Maximum: 0.47
King	A2	Rat (400 g)	(Cavity)	2.45	0.22 (estimate)	Sinusoid 60 Hz	Indeterminate	Indeterminate	60 s Repeated	0.6
Frey	A2	Rat (medium)	Various Orientations	1.2	0.35	Pulsed CW	0.2 2.4	2.1 mW/cm² 2.4 mW/cm²	30 min 30 min	Average: 0.07 Maximum: 0.86
Lin	A2	Rat	Near Field	0.918	0.9	CW	32 40	Not Applicable	15 min 5 min	7.2 8.9
M. Shandala	A3	Rat (medium)	Dorsal, Group	2.375	0.21	CW	0.01	Not Applicable	90 days	0.0021
Czerski	A3	Mouse (20 g)	Dorsal, Group	2.95	1.1	1 μs Pulses 1200 pps	0.5	420.0	6—12 wks	0.55
Huang	A3	Hamster (35 g)	Dorsal, Group Far Field	2.45	1.1	CW	5	Not Applicable	15 min/day for 5 days	5.5
Smialowicz	A3	Neonatal Rat (50—90 g)	Dorsal, Individual	2.45	0.7 — 4.7	CW	5	Not Applicable	60 days	0.7 — 4.7
Berman	A4	Mouse (25—33 g)	Dorsal, Group	2.45	0.8	CW	3.4 — 28.0	Not Applicable	100 min/day	2.0 — 22.2
Bawin	A5	Chick Brain *in vitro*	(Parallel Plate)	0.147	< .003	Sinusoid (0.5 — 32 Hz) AM > 90%	< 1	—	20 min	0.003
Blackman	A5	Chick Brain *in vitro*	(Crawford Cell)	0.147	< .002	Sinusoid (0, 3, 9, 16, 30 Hz)	0.75	—	20 min	0.0023

Table A1 (Continued)
Calculation of Whole-Body SARs for Data in Selected Reports

Research Paper	Reference	Subject and Mass	Orientation to *E* Field	Frequency (GHz)	W/kg per mW/cm^2	Modulation	Average Power Density (mW/cm^2)	Peak Power Density (mW/cm^2)	Duration of Exposure	Average SAR (W/kg)
Frey	A5	Rat (225 g)	Various Orientations	1.2	0.36 0.36	Pulsed CW	0.2 2.4	2.1 2.4	30 min 30 min	0.06 0.72
Albert	A5	Chinese Hamster (35 g)	Not Specified	2.45	1.0	CW	10	Not Applicable	1 h or 8 h for 1 day	10
Lovely	A9	Rat (316—388 g)	(Circularly Polarized Waveguide)	0.918	0.36	CW	2.5	Not Applicable	8/h/day for 13 weeks	0.9
Stern	A9	Rat (385—400 g)	Dorsal	2.45	0.18	CW	5	Not Applicable	15 min Intermittent	0.9
Adair	A9	Squirrel Monkey (1 kg)	Long Axis ‖ to E Vector	2.45	0.13	CW	6	Not Applicable	15 min Intermittent for 3 h	0.78
DeLorge	A9	Squirrel Monkey	Dorsal to Head	2.45	0.13	AM (120 Hz)	50	—	30—60 min	6.5
Lu	A9 A10 A11	Rat (150 g)	Dorsal	2.45	0.36	CW	1	Not Applicable	8 h	0.35
Travers	A11	Rat	Not Specified	2.45	0.21	CW	8	Not Applicable	8 h/day 0, 7, 14 or 21 days	1.65
Lovely	A11	Rat (300—350 g)	(Circularly Polarized Waveguide)	2.45	0.21	CW	0.5	Not Applicable	7 h/day for 3 months	0.11
Guillet and Michaelson	A12	Rat (Neonatal) (10—25 g)	Dorsal	2.45	1.3	CW	10	Not Applicable	1 h	13
McRee and Hamrick	A12	Japanese Quail Embryo (10 g)	Long Axis ‖ to E Vector	2.45	0.8	CW	5	Not Applicable	12 days	4
Johnson	A12	Rat (290—310 g)	(Waveguide)	0.918	0.5	CW	5	Not Applicable	20 h/day for 19 days	2.5
Mitchell	A14	Rat (300 g)	15/Group (Cavity)	2.45	0.5	CW	2.3	Not Applicable	1 or 5 h/day 110 days	1.2
Miro	A14	Large Mouse (26—38 g)	Horizontal	3.10	0.9	Pulsed 5 Hz—1 ms	2	Not Applicable	145 h	1.8
Reed	A15	Isolated Rat Heart	Parallel-Plate Exposure	0.96	—	CW	Indeterminate	Not Applicable	10 min	1.5

Table A2
Field Strengths (E and H) and Power Densities in Proximity to a Current-Fed, Quarter-Wave, Radiating Monopole Antenna

A 50 cm antenna operating at 150 MHz and 2 W of input power is assumed, as an input impedance of 36 Ω. Each asterisk associated with a set of field measurements denotes the spatial point of measurement in relation to the antenna. The vertical and horizontal distance between adjacent points of measurement is 10 cm. (Calculations based on [41].)

Distance in Centimeters				
0	10	20	30	40
E = 64.3 V/m H = 0.00 A/m PD = 1.10 mW/cm²	48.7 0.0217 0.628	32.7 0.0317 0.287	24.2 0.0341 0.156	19.3 0.0348 0.0985
*	*	*	*	*
	95.1 0.0524 2.40	45.7 0.0524 0.553	29.8 0.0489 0.236	22.4 0.0456 0.133
50 cm Monopole Antenna	*	*	*	*
	121 0.136 3.88	53.4 0.0856 0.757	33.3 0.0682 0.295	24.5 0.0533 0.159
	*	*	*	*
	110 0.229 3.72	51.7 0.124 0.708	33.3 0.089 0.300	25.0 0.0716 0.193
	*	*	*	*
	83.6 0.306 3.54	43.0 0.157 0.931	30.2 0.108 0.437	24.1 0.0531 0.261
	*	*	*	*
	50.1 0.358 4.82	32.0 0.180 1.22	26.2 0.120 0.548	22.7 0.0910 0.312
	*	*	*	*
	27.7 0.375 5.31	26.3 0.188 1.33	24.3 0.125 0.589	22.1 0.0938 0.332
	*	*	*	*

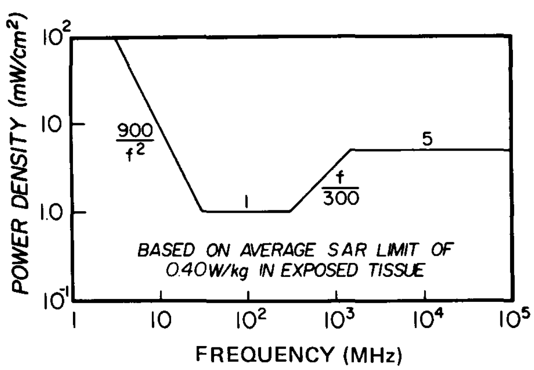
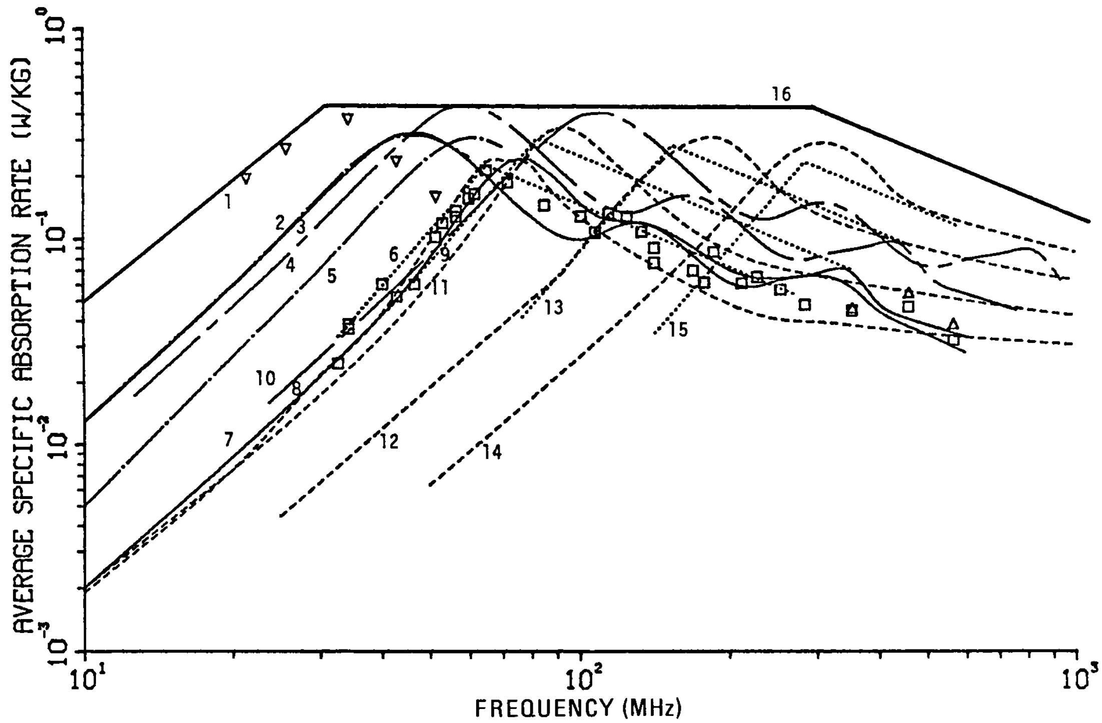


Fig A1
Radio Frequency Protection Guide for Whole-Body Exposure of Human Beings



(1) (Inverted Triangles). Experimental results scaled from a saline-filled, realistic model of an adult human being under grounded conditions.**

(2) (Solid Curve). Numerical calculations based on a block model of man in conductive contact with ground.†

(3) (Chain-Dot). Experimental results based on a realistic model of a human adult in conductive contact with ground.*

(4) (Chain-Dash). Scaling of Curve 2 for ten year old child in conductive contact with ground.

(5) (Chain-Dot). Experimental results based on a realistic model of a human adult 3 cm from a ground plane.*

(6) (Dotted Line). Empirical equation developed for a human adult in free space.**

(7) (Solid Line). Numerical calculations for a block model of man in a free field; experimental data are shown as open squares and experimental data on models are shown as open triangles.**†

(8) (Dashed Line). Prolate spheroidal model of man in a free field.*

(9) (Dotted Line). Empirical equations for a ten year old child.**

(10) (Chain-Dash). Scaling of Curve 2 for a one year old child in conductive contact with ground.

(11) (Dashed Line). Prolate spheroidal model for a ten year old child.*

(12) (Dashed Line). Prolate spheroidal model for a one year old child.*

(13) (Dashed Line). Empirical equations for a one year old child.

(14) (Dashed Line). Prolate spheroidal model of a human infant.*

(15) (Dot). Empirical equation for a human infant.**

(16) Upper limit of the SAR for human beings of all ages and body mass.

*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, 1978.

**GANDHI, O. P., HUNT, D. L. and D'ANDREA, J. A. Deposition of Electromagnetic Energy in Animals and in Models of Man With and Without Grounding and Reflector Effects. *Radio Science*, 12(6S), 1977, pp 39—48.

†HAGMANN, M. J. and GANDHI, O. P. Numerical Calculations of Electromagnetic Energy Deposition in Models of Man with Grounding and Reflector Effects. *Radio Science*, 14(6S), 1979, pp 23—29.

Power Density = 1 mW/cm². The results of various investigators are used for cross comparison. The outer envelope, curve 16, is the upper-limit SAR for the range of human beings from infant to adult (see legend).

Fig A2
Whole-Body-Averaged SAR for a Human Adult, a 10 Year Old Child, a 1 Year Old Child, and a Human Infant

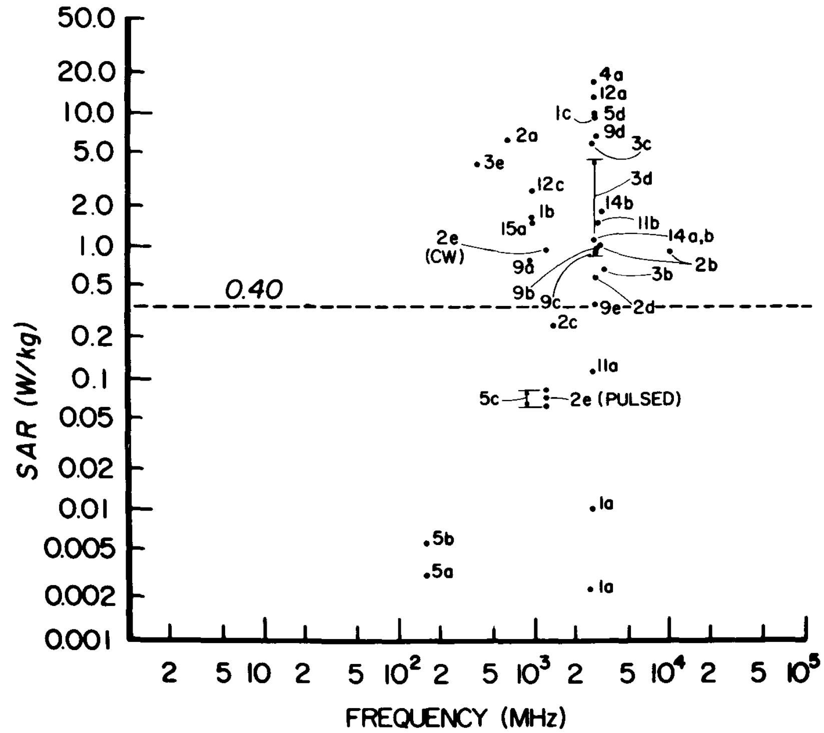


Fig A3
Whole-Body-Averaged SAR
Corresponding to Biological Effects Reported in
Various References of Appendix