RADIATION HAZARDS

We are, from the moment of conception, bathed in a sea of electromagnetic waves. Some of these waves are benign or even beneficial, while others are definitely harmful. Part of this radiation is natural and part is man-made. Natural radiation includes the light, radio-waves and cosmic rays from the Sun, Moon and stars; background radiation from the rocks, soil, water and atmosphere of our planets; and the internal radioactivity of our own bodies. Man-made radiation, which forms an increasingly large proportion of the whole, includes radio and radar waves.

It is obvious that we must be more or less immune to any kind of radiation which normally reaches us from outer space, yet earthworms are killed by sunlight even when kept damp and cool, and occasionally human children are born who are abnormally photosensitive and eventually die from the effects of sunlight. Moreover, sunlight can induce skin cancer as well as an attractive tan, and certain drugs have a strongly photosensitizing effect, which makes it necessary for patients who are taking them to use a barrier cream against the enhanced action of ultraviolet rays.

Magnetic Fields:

It would seem logical that the highest field strengths would be associated with the greatest detectable biological effects; however, the present literature does not support this thesis. While a host of relatively minor effects upon lower animals are reported, the most significant effect of high strength field exposure in mammals appears to be alterations in the electrical activity of the central nervous system, with possible associated pathological lesions in the brain. It would at this time, therefore, appear desirable to avoid exposure of humans (either total body or head alone) to field strengths in excess of 1,000 gauss, which might be found in the near vicinity of magnetohydrodynamic (MHD) equipment, in attempts to control atomic fusion reactions by intense magnetic fields, very large D.C. electrical transmissions, such as in the aluminum smelting industries, and in magmetic separation procedures, for anything other than short time periods. In particular, the suggestion to utilize magnetic shielding against radiation for space capsules, should also be most carefully evaluated before being put to use. Another caution would be in the application of high strength fields modulated at certain frequencies. Since certain definite effects seem to be associated with low strength, low frequency (0.1 - 0.2 Hz) fields, human exposure to high strength similarly modulated fields should definitely be avoided except under controlled experimental conditions.

Safe RF Fields:

The "magic" number for determining a radiation hazard condition is the field strength 10 milliwats per square meter. An explanation of how this value was derived can be found in the Handbook on *Radio Frequency Radiation Hazards* (T.O. 31-1-80) dated 15 April, 1958, published under authority of the Secretary of the Air Force. Two pertinent paragraphs are excerpted as follows:

"Based on evidence given in paragraph 1-7, that injury had been caused to experimental animals and could possibly be caused to personnel, all available information was researched in an effort to establish a safe exposure level to this form of possible injury. Many variables were considered, such as the frequency of the energy to which an individual may be exposed, the nature of the exposure, including time of exposure, field strength, and other aspects.

Sufficient factual data is not available to determine the safe exposure level for each frequency; therefore, it was decided to select one level satisfactory for all frequencies. Past research indicated that a power density of 0.2 watts/cm^2 was required to produce damage. The accuracy of the methods and instrumentation used was somewhat questionable, and possibly some cases of reported damage might have been caused by power densities of approximately 0.1 watts/cm^2. The expanded use of electronics has also resulted in adding minute amounts of microwave energy from incidental sources at many frequencies. Since it is impractical to measure the power density at each of these frequencies separately, and since the sum of all these assorted r-f sources would be extremely small, a safety factor of 10 was selected and the present USAF level of 0.01 watts/-cm^2 was established.

NOTE

Incidental sources do *not* include other high power electronics equipment in the vicinity.

This level of 0.01 watts/cm^2 is an *average* power level and not peak power, since available data indicates the only detrimental effects are thermal in nature, and these effects depend upon average and not peak power levels. Sufficient data is not available to furnish complete correlation between length of exposure and power density. The present level of 0.01 watts/cm^2 is the maximum for either continuous or intermittent exposure, and precautions should be taken to avoid exposure of personnel to ambient power levels in excess of 0.01 watts/cm^2 for any period of time."

In October of 1961, T.O. 31-1-80 was superceded by T.O. 31Z-10-4. The revised handbook went deeper into the problem, but maintained the 10ms/sq. meter magic value. One of the new aspects introduced was the relationship of man's physical size to wavelength. It states that when considering the biological effects produced by r-f radiation, the wavelength (frequency) of the energy and its relationship to the physical dimensions of objects exposed to radiation become important factors. It has been determined that for any significant effect to occur, the physical size of the object must be the equivalent of at least a tenth of wavelength at the frequency of radiation.

Practically speaking, the human body is a three-dimensional mass having width and depth, as well as height. Therefore, when a man stands erect in an r-f field, he represents an object which not only has a height dimension, but also has width and depth dimensions that can be expressed in terms of wavelength. Again comparing the physical characteristics of the human body to those of a broadband receiving antenna, when the body is oriented so that any of these major body dimensions is parallel to the plane of polarization of the r-f energy, the effects produced are likely to be more pronounced than when the body is oriented to other positions.

The penetration of energy into the body and its absorption (loss of energy), and reflection will depend not only upon the physical dimensions and dielectric constant of the tissues, but also upon the frequency (wavelength) of the r-f radiation.

The handbook also discusses the frequency-dependent characteristices of whole body exposure. It states that the percentage of absorbed biologically effective energy approaches 40 percent of the incident energy for frequencies below 1000 mc (30 cm) and for frequencies above 3000 mc (10 cm).

The percentage of absorbed biologically effective energy is between 20 and 100 percent of the incident energy for frequencies between approximately 1000 and 3000 mc (30 to 10 cm wavelength).

The sensory elements of the body are located primarily in the skin tissues; for this reason radiation frequencies below 1000 mc are considered extremely hazardous because the presence of r-f radiation will not be detected by the human sensory system. Radiation at frequencies below 1000 mc causes heat to be developed primarily in the deep tissues as a result of the penetration of the energy. The energy absorbed in body tissues may be as high as 40 percent of the incident energy arriving at the body surface.

Frequencies greater than approximately 3000 mc cause heating of tissues in much the same manner as does infrared radiation or direct sunlight; therefore, the sensory reaction of the skin should normally provide adequate warning of the presence of r-f radiation. In general, the depth of energy penetration decreases rapidly with an increase in radiation frequency, and absorption occurs almost completely in the surface of the body where skin tissues and the sensory elements are located. Also, reflection of energy at the surface of the skin occurs at the higher frequencies. Thus, the percentage of energy abosrbed may approach 40 percent of the energy incident on the body surface, with a greater portion of energy being reflected.

Radiation at frequencies between 1000 and 3000 mc is subject to varying degrees of penetration and is abosrbed in both surface tissues and deeper tissues, depending upon the characteristics of the tissues themselves (thickness, dielectric constant, and conductivity) and the frequency of radiation. The percentage of incident energy absorbed varies from approximately 20 to 100 percent because of tissue factors governing impedance values, which range from complete mismatch, to a near perfect match, to the incident energy.

When electromagnetic energy is absorbed in tissues of the body, heat is produced in the tissues. If the organism cannot dissipate this heat energy as fast as it is produced, the internal temperature of the body will rise. This may result in damage to the tissue and if the rise is sufficiently high, in the death of the organism. The body's ability to dissipate heat successfully depends upon many related factors, such as environmental air circulation rate, humidity, air temperature, body metabolic rate, clothing, power density of the radiation field, amount of energy absorbed, and duration of exposure (time).

The limited ability of the body to dissipate heat when its temperature is elevated above normal is complicated by the fact that the basal metabolic rate increases as much as 14 percent for every degree of temperature rise above normal. The increase in temperature also causes abnormally rapid breathing, or fever hyperpnea. The lack of oxygen available in the blood for release to cells or tissues results in hemorrhages and damage to the brain cells, the central nervous system, and certain internal organs, and may also result in muscular irritability and sometimes convulsions. If these conditions persist, the results are usually coma and eventual death.

Certain organs of the body are considered to be more susceptible than others to the effects of r-f radiation. Organs such as the lungs, the eyes, the testicles, the gall bladder, the urinary bladder, and portions of the gastrointestinal tract are not cooled by an abundant flow of blood through the vascular system. Therefore, these organs are more likely to be damaged by heat resulting from excessive exposure to radiation. Of the organs just mentioned, presently available information and experience indicate that the eyes and testicles are the most vulnerable to microwave radiation.

Russian Regulation:

Report number AD 278 172 is based on a translation of a book by Professor A.A. Letavet and Decent Z.V. Gordon of the Institute of Labor Hygiene and Occupational Diseases of the Academy of Medical Sciences, U.S.S.R. The book is dated, Moscow, 1960 and bears the title, "The Biological Action of Ultrahigh Frequencies."

The following general effects of chronic exposure of humans to microwave energy were reported:

a. Bradycardia, or an inhibiting effect on the rhythm of heart contractions.
b. A disruption of the endocrine-humeral processes.
c. Hypotension, or low blood pressure.
d. Intensification of activity of the thyroid gland.
e. An exhausting influence on the central nervous system.
f. A decrease in sensitivity of the sense of smell.
g. An increase in the histamine content of the blood.

The report goes on to state that U.S. Army Regulation AR 40-583, dated 12 July 1961 specifies 10 milliwatts per square centimeter as a permissible limit for exposure of humans to microwave energy. The Russian safety regulations for exposure of humans to microwave energy are so much more stringent than those specified in AR 40-583 that the permissible limits are here reproduced for emphasis:

"The microwave radiation intensity in areas where personnel are required to be present should not exceed the following maximum permissible values:

a. In the case of irradiation during the entire working day - no more than 0.01 milliwatts/cm^2.
b. In the case of irradiation for no more than two hours per working day - no more than 0.1 milliwatts/cm^2.
c. In the case of irradiation for no more than 15 to 20 minutes per working day - no more than 1.0 milliwatt/cm^2. (In this case the use of protective goggles is mandatory.)"

FCC Safety Guidelines

As far as the FCC is concerned, harmful radiation could come from FM and TV stations. (Ref. 3). As yet radiation hazards have not been considered by the Commission in its spectrum management procedures. With the trend toward higher effective radiated powers, such hazards might become a factor in the allocation of VHF-UHF facilities.

Various governmental and industrial organizations involved in establishing of the radiation safety standards have recommended exposure limits referred to as Radiation Protection Guide Numbers (R.P.G.N.), described by Mumford (Ref. 1). At present, the generally accepted R.P.G.N. values are 10 and 1.0 milliwatts per square meter for temperature-humidity indices (THI) of 70 or less, and 79 or greater, respectively. When the THI is between 70 and 79, R.P.G.N.=(80-THI) milliwatts/cm^2.

The most direct approach to providing protection from radiation exposure is the determination of minimum protection distances from radiation sources for specified R.P.G.N.'s. Since the protection distance from a radiation source depends on its radiated power in a given direction, a distance vs. radiated power relationship is most useful and is presented in Fig. 1 for R.P.G.N.'s of 1 and 10 milliwatts per square centimeter, respectively. An isotropic point source was assumed at the center of radiation and power densities W calculated from equation:

$$W = \frac{P}{4\pi R^2},$$

Where

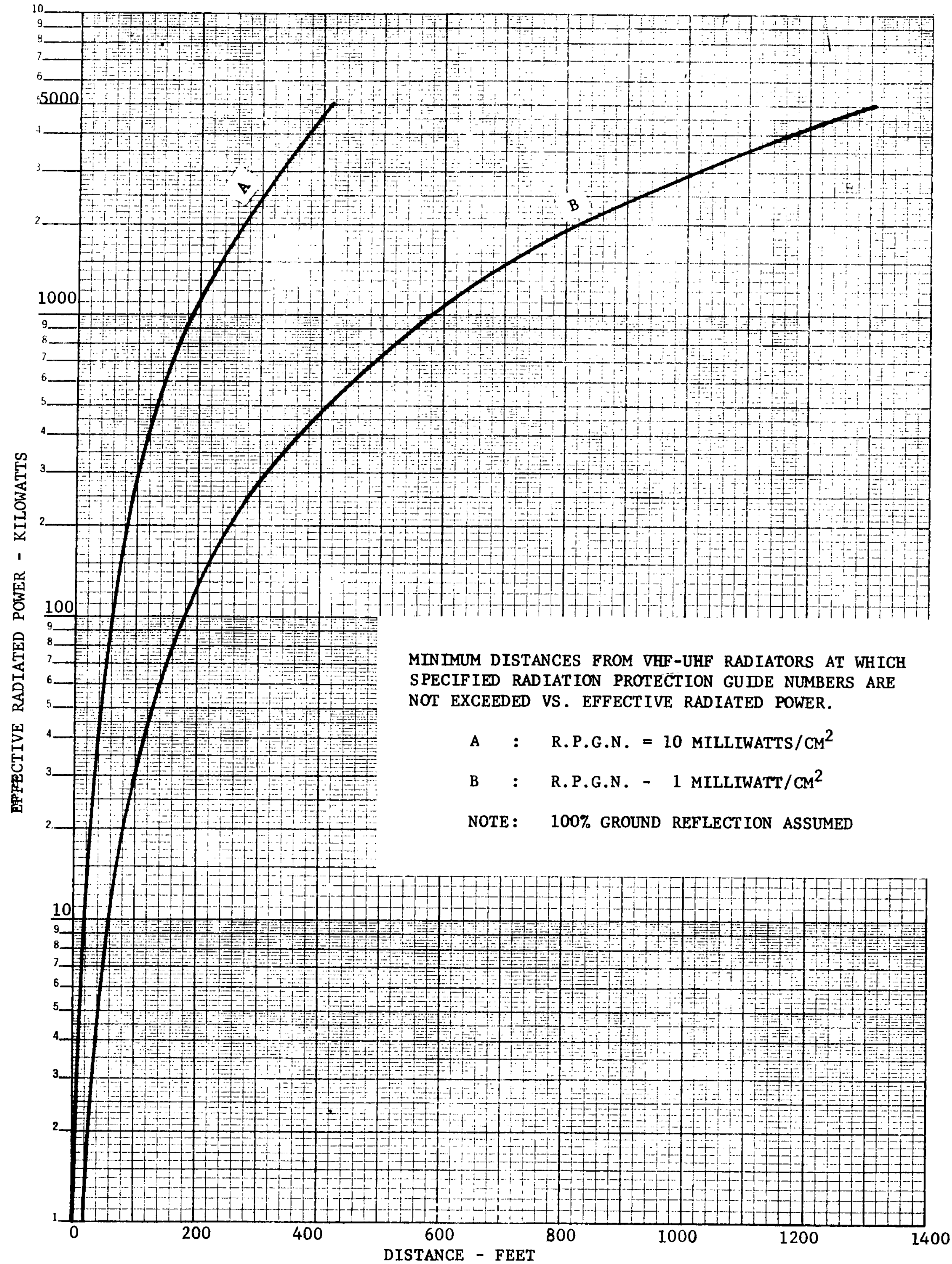
W = power density in watts per square meter
P = effective radiated power in watts
R = distance in meters
π = 3.1416

The curves in Fig. 1 were calculated assuming 100% ground reflection, which doubles the electric field strength and quadruples the power density as described by Mumford (Ref. 2). This assumption is likely to result in a conservative estimate of the required minimum distances. For free-space power densities such distances would be halved.

In an actual case involving a source of potential radiation hazard, its radiated power in the pertinent direction would be used in conjunction with the attached curves to determine the required protection distance. If calculations based on these curves indicated that there may be a problem, then the actual antenna system of the potential hazard would have to be considered, and extensive calculations of the near field would be required.

References

1. W. W. Mumford, "Heat Stress Due to R. F. Radiation," Proc. IEEE, Vol. 57, pp. 171-178, February 1969
2. W. W. Mumford, "Some Technical Aspects of Microwave Radiation Hazards," Proc. IRE, Vol. 49, pp. 427-447, February 1961
3. J. Damelin, "VHF-UHF Radiation Hazards and Safety Guidelines," FCC Report No. 7104, July 19, 1971


MINIMUM DISTANCES FROM VHF-UHF RADIATORS AT WHICH SPECIFIED RADIATION PROTECTION GUIDE NUMBERS ARE NOT EXCEEDED VS. EFFECTIVE RADIATED POWER.
A : R.P.G.N. = 10 MILLIWATTS/CM^2
B : R.P.G.N. - 1 MILLIWATT/CM^2
NOTE: 100% GROUND REFLECTION ASSUMED
A
B
EFFECTIVE RADIATED POWER - KILOWATTS
DISTANCE - FEET
5000
1000
100
10
1
0
200
400
600
800
1000
1200
1400