Glaser

by John Osepchuk

Summary of Testimony Prepared for Public Hearings,
Power Facilities Council, May 31, 1979

Madame Chairperson, Members of the Council, ladies and gentlemen, I am happy to testify at your hearings on the subject of "microwaves," their hazards and the relation of these subjects to telecommunication towers of interest to the Council.

In the last ten years I have seen the subject of "microwaves" and the hazards thereof develop among much misinformation in the mass media. There is a committee of the Institute of Electrical and Electronics Engineers which has fought this misinformation or propaganda campaign since 1972. This is the Committee on Man and Radiation (COMAR) of which I am a member. In 1977 I testified as a member of COMAR before the U.S. Senate and reviewed the status of COMAR's fight and pointed out the need for a rational perspective. I attach a copy of that testimony as an Appendix to my presentation today. Please note the paper by Dr. Don Justesen, COMAR Chairman, which is attached to that testimony. It stresses the existence of irrational fears which are still present today and which I hope to dispel.

It is impossible to discuss this subject intelligently without learning some of the basic terms and how to interpret some of the numbers attached to these terms. It should be clear that unless we talk in terms of numbers we will be bogged down in rhetoric like "it is known that 'microwaves' can kill." One can say the same thing about water, salt, sugar or practically any entity. "Voltage" can kill if it is the voltage of a high-voltage line whereas nobody seriously worries about the voltage on a flashlight battery. Sometimes the press seems to resist the need to discipline their writing by such restrictions - hence some of the confusion and misapplied fears. Hopefully we can restrain our discussions to conform to some fundamental rules. To help understand these rules I will try to present a brief explanation of what "non-ionizing" radiation is; how and why it is absolutely different from ionizing radiation; what is "microwaves," and how is this energy measured.

"Microwaves" are a special type of "electromagnetic waves" or "fields" which in general includes some perhaps more familiar waves like visible light, infrared, radio, and household electricity. All these types of energy radiate as waves as depicted in Fig. 1. We show a wave "propagating" in the x-direction. One can imagine the whole disturbance moving with unchanged form much as one sees waves move on the surface of water ("radiate" or "propagate"). The disturbance that is the essence of electromagnetic waves is analogous to the mechanical forces that make the water move up and down and is described by quantities called "fields". There is an "electric" field oriented in a transverse direction like y. One can picture this as the quantity that exists between two electrodes with a battery across them. Thus the electric field is a quantity expressed in volts per meter (or cm). This field has the ability to move charges which exist in all matter in one form or another. Therefore, we can expect this field to interact with materials, particularly the dielectric materials (including food) and metals. One can imagine currents, or charges in motion, within the material induced by this field. Because the wave is moving or propagating, however, charges in the material which are essentially at rest, see not a steady field or force but one which alternates in direction at a rate called "frequency".

Also in Fig. 1 we show a magnetic "field" oriented at right angles (perpendicular) to the electric field. This also will cause currents in metals but is not of basic importance in interacting with dielectrics, which includes foods. These magnetic fields are more important if the material is "magnetic", e.g., a "ferrite". Magnetic fields (H) are described by units of amps/meter or oersteds. The other form B of magnetic field is measured in terms of "Tesla" or gauss.

All electromagnetic waves move with the same velocity in free space, namely 3×10^{10} cm/sec or 186,000 miles/second. This is difficult to conceive but frequency and a quantity called "wavelength" are more easily appreciated. The "wavelength" is simply the distance or period between neighboring points of similar or the same field - magnitude and direction - analogous to the distance between peaks of water waves. The wavelength is expressed in meters or centimeters.

Now since the disturbance or wave is moving at a speed of $c = 3 \times 10^{10}$ cm/sec. the sense of the field experienced at a fixed point varies or oscillates, repeating itself periodically, at a rate equal to the distance the wave moves in one second ($c = 3 \times 10^{10}$ cm) divided by the distance between field peaks (i.e., λ) - i.e., the number of positive or negative peaks that sweep by in one second. This is the frequency f and the calculation simply is

$$f = \frac{c}{\lambda} \qquad (1)$$

Material objects, including materials with charges, experience <u>different</u> results in being shaken at <u>different</u> rates or frequency. Imagine a swing being pushed very slowly so that it moves with you, then pushing it in "resonance" with its natural motion and then shaking it in cyclical fashion as fast as we can, e.g., 3-4 cycles per second. Clearly very different things happen depending on frequency. In the same way matter with its different chemical and atomic constituents has a variety of natural frequencies so that the effects of its interaction with electromagnetic fields will vary greatly with frequency.

To help to understand the penetrating quality of microwaves in such materials as biological tissue, consider what happens when an electromagnetic wave is incident (is directed toward) on an infinite plane surface of such a material. This situation is sketched in Fig. 2. In general, a substantial amount is reflected in optical fashion and an also substantial amount is transmitted into the substance with a change of direction called "refraction" (the same principle involved in the apparent shift of an object position under water when viewed from above the water). The energy transmitted into the substance, however, is progressively absorbed or attenuated so that the wave decreases in magnitude as it penetrates into the material. The rate at which this happens can be described by a "penetration depth" D (or skin depth) that is variously defined but here defined as the depth at which the power level of the wave is decreased by 86.5% ($1/e^2$). This means that 86.5% of the power is absorbed between the surface and the penetration depth. It also means that at distances into the material substantially greater (e.g., > 2D) than the penetration depth, the wave is weak and negligible heating occurs when it is attempted as in diathermy.

The larger tan δ, the smaller the penetration depth, and a higher dielectric constant reduces D.

The energy or power absorbed by the body as the wave attenuates produces local heating at a rate called the "specific absorption rate" and is denoted by the term SAR which is proportional to tan δ and the square of the internal E field.

Examples of various materials and their properties at the common microwave frequency of 2450 MHz are shown in Table I. Paper and plastics are transparent but foods and biological tissue are heavy absorbers.

Now that we have some basic concepts of electromagnetic waves, let us see what kinds of numbers or values these quantities have for the various types of EM waves with which we are familiar.

This information is depicted in what we call the electromagnetic "spectrum" which simply is the chart in Fig. 3 designating in order different ranges of frequency (cycles per second or Hertz) and wavelengths (centimeters) for the different already named types of energy. (Note that frequency and wavelength are inversely related through Eq. (1) and either quantity by itself specifies the waves under discussion.)

The chart demonstrates that alternating current power, i.e., household electricity, is at 60 cycles per second or 60 Hertz. In this case it is easier to conceive the frequency of 60 times per second than the enormous wavelength of 5×10^8 (500 million) centimeters or 5000 kilometers. At the other end of this part of the spectrum of interest to us is visible light. (This part is called "non-ionizing" radiation.) At this end, optical frequencies of 10^{15} Hertz are difficult to conceive while the wavelength is a bit easier to appreciate, e.g., 1/100,000 of a centimeter or about 1/1000 the diameter of a human hair.

TABLE I

A Partial List of Dielectric Properties of Foods and Other Materials at 2450 MHz (at room temperature, 20° C)

Material	ε	tan δ
Distilled Water	78	.16
Muscle	50	.422
Fat	9	.268
Raw Beef	49	.33
Mashed Potato	65	.34
Cooked Ham	45	.56
Peas	63	.25
Ceramic (Aluminum)	8 - 11	.0001 - .001
Most Plastic	2 - 4.5	.001 - .02
Some Glasses (Pyrex)	∿ 4.0	∿ .001 - .005
Papers	2 - 3	.05 - .1
Woods	1.2 - 5	.01 - .1

At this point I must stress some important distinctions of "non-ionizing" radiation and "ionizing radiation." The latter is the type associated with medical x-rays, nuclear power plants etc. Recently, after the Three-Mile Island incident, two out of three leading national news weekly magazine confused microwaves with the "radiation" of concern near nuclear power plants. A leading researcher on microwave bioeffects wrote one of the magazines and pointed out the serious error. He stated that to include microwaves with the "radiation" of nuclear power is like including falling marshmallows with high-speed rifle bullets in the general category of "projectiles." Amazingly, the news magazine still did not appreciate the need to distinguish these different radiations.

The technical aspect associated with this great difference is "quantum energy" (Fig. 3). The ionizing radiation have frequencies greater than that of light and "quantum energies" in terms of many thousands of volts or even millions of volts. This means that even the smallest amount of ionizing radiation can damage a molecule and then possibly a cell. In contrast, the "microwaves" have quantum energies of the order of a millionth (1/1,000,000) of a volt - much smaller an influence on a molecule than the normal thermal fluctuation which any molecule is subject to from neighboring molecules. Infrared energy, the heat waves we experience from the fireplace or the surface range, has much higher quantum energy than microwaves but still too small to ionize.

The reason why this distinction is important is as follows. Because even the smallest amount of ionizing radiation is potentially destructive, it is common to assume that there are no thresholds for hazards, i.e., no absolutely safe level and all small radiation exposures can be cumulative, i.e., they add up in time.

On the other hand, non-ionizing radiation is not cumulative in its actions at very low levels, i.e., it is generally assumed that there are thresholds for effects and hazards. Below thresholds there is absolute safety. Thus nobody suggests that one can get a burn by standing 20 feet from a household fireplace from the heat radiated.

In the same way it will be seen that there are safe levels of "microwaves" and once well below safety limits it is irrational to worry.

In between visible light, for which we all have a feeling of straight line propagation of rays or waves, and household electricity which gives us a feeling for volts, amperes and watts, lie microwaves with some relation to both ends of the spectrum, i.e., both the E and H fields and such radiation terms as power flux density (milliwatts/cm^2) are important in describing microwave effects.

In the microwave frequency range, optical effects like those of visible light or infrared, well known "heating" waves, are still of some significance. But it also requires some use of such low frequency concepts as voltage, field and current which describe radio waves. Television broadcasting is located within the microwave range as we define it. The microwave oven frequencies are at 915 MHz and 2450 MHz, two of the so-called ISM bands (industrial, scientific and medical).

We now note that telecommunication towers generally operate between 2 GHz and 20 GHz - well above radio and TV frequencies.

The definition of the microwave portion of the electromagnetic spectrum is somewhat arbitrary but can be based on the property of maximum coupling of electromagnetic energy to macroscopic objects of common use and interest to man. On this basis one can defend 10 MHz 30 meter wavelength) to 100 GHz (3 millimeter wavelength) as the microwave range. It is expected that the heating, cooking and biological effects of non-ionizing radiation depend on the "penetrating power" of the radiation and the latter is expected to peak in the microwave region as shown in Fig. 4, which is a rough calculation of the field in the center of a man when exposed to radiation of a given frequency.

At low frequencies the radiation or field is shunted out (or reflected) by the conducting nature of the body. (The dielectric constant also becomes very large at low frequencies.) At high frequencies the energy is absorbed in a small skin depth. Thus internal field is large only in a finite range which we can call "microwave". This depends on animal size, and is located at 100 MHz for man and at 3 GHz for a mouse.

"Power" Density and Radiation Fields

The term "radiation" when applied to any non-ionizing radiation applies only in the "far-field" of some radiating source where there is a radiating plane-wave (Fig. 1) with certain unambiguous relationships between E and H fields and power flux or power density. In this case the power density is related to E field by

$$p_o(W/m^2) = \frac{E^2(V/m)}{120\ \pi} \tag{2}$$

or

$$p_o(mW/cm^2) \cong \frac{E^2(V/m)}{4000} \tag{3}$$

The H field is also given by

$$H\ (A/m) = \frac{E(V/m)}{120\ \pi} \tag{4}$$

and the B field is given by

$$B(\text{gauss}) = \frac{E(V/m)}{30{,}000} \tag{5}$$

At high frequencies, above microwaves, both the field concepts and power flux, have value and an interrelation as given above. At low frequencies, however (i.e., below microwaves) it is quite possible to have either E or H fields without the other and without significant radiation. In such fields, which we call quasistatic, no definite relationship exists between the E and H fields at any given point.

<u>Relation of Radiated Power to Power Flux</u>

It is useful to review the relationship between radiated power in watts to radiation density in mW/cm^2 to gain some perspective on how much power is required to produce a given power density over some area at some distance.

Consider the various radiating sources or antennas depicted in Fig. 5. The isotropic source (d) radiates in all directions, and the power density therefore varies as the inverse square of the distance from the source, the inverse square law. In mixed units one can write

$$P_{rad} = 11.67\ R^2\ p_o \tag{6}$$

where P_{rad} is the radiated power in watts, R is the distance to source in feet, and p_o is the power flux at distance R from the source, in milliwatts/cm^2 (mW/cm^2).

If the small source is constrained to radiate into the half-space as in (c), then only half the power is required for the same p_o at R as in (11), i.e.,

$$P_{rad} = 5.84\ R^2\ p_o \tag{7}$$

for case (c). In antenna terms one has achieved an antenna gain of 2 or 3 dB where Gain = Effective-Radiated Power/Actual Power - the effective radiated power (ERP) being that power that when radiated isotropically yields per (10) the same power density at R as is the actual case.

The case (c) corresponds roughly to microwave oven or any other localized microwave leakage. The rapid decrease of power density is depicted in Fig. 6 for various radiated powers. At a distance of a few feet, powers over 100 watts are required to produce power fluxes of $\sim$ 1 mW/cm^2.

Returning to Fig. 5 we see that in (b) a small aperture antenna is constrained to be somewhat directive although the energy quickly spreads after a short distance, i.e., a case of low gain where the antenna dimensions $D \sim \lambda$.

Finally, if a large aperture antenna (Fig. 5 (a)) is used where $D >> \lambda$, then high gain is achieved so that the beam is constrained to radiate into a small solid angle. The radiation still follows an inverse square law beyond the boundary of near and far fields given arbitrarily by $L \sim \frac{D^2}{2\lambda}$. In the general case, the power density at distance R is

$$p_o = \frac{G\ P_{rad}}{11.67\ R^2} = \frac{(ERP)}{11.67\ R^2} \tag{8}$$

where G is the antenna gain and G can be written as

$$G = \frac{4\pi A_e}{\lambda^2} \quad (9)$$

where A_e is the effective aperture of an antenna. This aperture is approximately the physical aperture of a large paraboloid reflector, for example.

High values of gain typically vary from 100 (20 dB) to 1000 (30 dB) - the former is more typical for television antenna arrays which radiate an annular beam (vertical gain only) and the latter is typical for higher microwave frequency radars which radiate a spot beam with both vertical and horizontal gain. Although almost all the power is radiated in the desired direction a negligible though possibly significant percentage is radiated in undesired directions. Thus a high gain radar may produce power densities 1000 times smaller than the main beam in directions up to 60° off the main beam - i.e., sidelobes. Sidelobe levels may decrease to as low as 1/100,000th of main-beam power density in the direction opposite to the main beam.

Whatever the gain for a given amount of power, a given power density can be produced only over a finite area as depicted by the simple plot in Fig. 7. For example, a power density of 1 mW/cm^2 when existing only in a very narrow area such as 0.01 square feet near a leakage source represents only about .01 watt radiated. But if this power density is assumed to exist over a beam area of 10,000 square feet, then clearly at least about 10 kilowatts must be radiated. Significant heating levels over an area of the human body (about 10 square feet) require powers of hundreds of watts. Larger powers can produce such heating densities over proportionately larger areas or concentrate more intense heating into the area of a man.

With reference to Fig. 5 it seems obvious that radiated power can be concentrated into an area such as the human body (10 ft^2) at some distance only if the frequency is high so that $D^2 \sim 10\ ft^2$ and $D \gg \lambda$. This occurs above 3 GHz - i.e., the higher microwave frequencies and is one reason why early investigators saw more potential hazard in "microwaves" than lower frequencies which could not be so focussed or directed.

Now in Fig. 8 we show a map of "intensity" benchmarks showing levels of natural and manmade radiation levels. It is true that naturally generated radiation is a minimum in the microwave range - more energy existing naturally at very low frequencies and in the infrared. Note, however, that the microwave emission density from the human body is of the order of 1/3 microwatt/cm^2.

Note also that though power density levels of mW/cm^2 or even watts/cm^2 or higher equivalent fields can be easily tolerated by man in the non-ionizing range.* However, by comparison a lethal dose rate of x-rays might be of the order of 1/1000 μW/cm^2 or 1/1,000,000 mW/cm^2. Again this clearly indicates a vastly different entity. Note that we use infrared or microwave for beneficial heating of the body whereas a lethal dose of x-rays raises the body temperature less than 1/1,000,000 of one °C.

In Fig. 8 the levels of radiation are expressed in power density at the high end of the NIR spectrum. At the low end of the spectrum the levels are expressed as E and B fields. The scale of fields is calibrated to agree with far-field relationships with radiation power density. Thus the E and B field scales on the left are the field levels associated with power density on the right. On the other hand, at low frequencies either or both E and B fields could exist without any meaningful power flux, i.e., quasistatic fields.

Now what are the types of "microwave fields" we are and have been exposed to - and I will stress "whole-body" fields - the quantity related to bioeffects and safety standards. (Obviously a strong field in a small needle-like hole is of less consequence than a field that is pervasive in space.) We list some typical data.

*at some frequencies and for short durations

TABLE II: A List of Commonly Encountered Microwave Fields

Source	Frequencies	
FM Radio Broadcast	80-100 MHz	Up to 1 $\mu W/cm^2$ at distance[1] of a mile from a transmitter
Broadcast Television	VHF: 50-250 MHz UHF: 450-900 MHz	up to 1 $\mu W/cm^2$ at a distance of a mile. Average value is $\sim$ 0.02 $\mu W/cm^2$ in suburban areas
FM and TV Broadcast	"	In high building levels[2] of the order of 100 $\mu W/cm^2$
CB Radio	27 MHz	10-100 $\mu W/cm^2$ a few feet from an antenna
Amateur Radio	Mostly HF and VHF	> 1 $\mu W/cm^2$ at distances of tens of meters from antenna
Mobile Radio	VHF, UHF	> 1 $\mu W/cm^2$ at distances of tens of feet
Microwave Ovens	2450 MHz	1-100 $\mu W/cm^2$ maximum for typically short durations
Microwave Relay Towers	2-20 GHz, typically < 5 watts	Maximum level on ground[3] typically of the order of 1/1,000,000 $\mu W/cm^2$ - possibly up to 1/1000 $\mu W/cm^2$
Radars	1 - 10 GHz	$\sim$ 10^{-3} $\mu W/cm^2$ a few miles away[4]
Diathermy	27, 2450 MHz	Hundreds of mW/cm^2 on patient. 0.1-1.0 mW/cm^2 a few feet away

We see the striking fact that levels that the general public can be exposed to due to microwave relay is much smaller than levels from broadcast, CB, or other radios. All the latter are believed to be safe. Still they produce environmental levels thousands or millions greater than that from microwave relay.

Now what are the safety levels? Well, in Fig. 9, we show some standards that apply in the range of 2-20 GHz. Typical exposure levels due to microwave relay are below the bottom end of the chart - insignificant levels. Shown are U.S. standards and the U.S.S.R. occupational standard. Note all standards are functions of time (exposure duration) and are time-average quantities.

Now there is a proposed safety limit in the U.S.S.R. for the general public which goes down to 5 $\mu W/cm^2$ for long duration. In both the West and the East, there are now proposals to establish the lowest safety limits in the rough range of FM radio and VHF television, i.e., 30-300 MHz, e.g., 1 $\mu W/cm^2$ proposed in the U.S.S.R., $\sim$ 1 mW/cm^2 proposed in the West. At frequencies below 30 MHz all countries agree that safety limits can be loosened in the upward direction rapidly as frequency decreases.

Now we se that there are still discrepancies between safety limits in the U.S. and U.S.S.R. Much of this is due to differing amount of safety factor. The rest is due to protection against different things - thermal damage in the West - and subtle behavioral (reversible) effects in the East. In any case, thresholds for health effects are assumed to exist and below these thresholds there is perfect safety.

Lastly, in Fig. 10, we show some curves describing how the body of man varies with frequency in its susceptibility to absorb microwave energy. Note at frequencies of microwave relay that average absorption is almost a factor of 10 below the peak resonance value which occurs at $\sim$ 80 MHz in the center of the FM and VHF TV bands. Furthermore, energy absorbed at > 2 GHz penetrates only a few centimeters. Energy at $\sim$ 80 MHz however is potentially deeply penetrating.

Thus the <u>frequencies</u> of microwave relay are potentially much less hazardous than those of CB, FM, TV and other radio.

At this point we can state with certainty that there is no microwave exposure hazard from microwave relay towers. Furthermore, we can state that the potential exposure levels are not only thousands or even millions below exposure levels from most prevalent sources of microwaves but also the frequencies are potentially much less hazardous. In fact, the level absorbed near a human body is at least a thousand times greater than exposure levels from microwave relay.

Finally, what is modern bioeffect research coming up with? In short, the key results are various effects with small rodents at levels of the order of 1 - 10 mW/cm^2 in their resonant frequency ranges. If scaled to man, this has implications applying in the resonance range for man. In any case, the preponderance of Western thinking is that these effects are all explainable by deep body heating - even at mild heating rates. Thus there appears little chance that U.S. safety limits will be lowered greatly except in the resonance range, e.g., < the order of 1 mW/cm^2. On the other hand, there is some suggestion that in time the U.S.S.R. will raise its limits. Poland has already raised their limits in recent years.

In conclusion, we can state that there is no microwave exposure hazard from microwave relay systems. We also believe that existing ambient levels from radio and TV are safe. Because the latter are thousands or more higher than levels from microwave relay any honest concern in this area would first begin there and not with microwave relay. Note we know of no restrictions on microwave relay towers due to fears of microwaves anywhere in the world, including the U.S.S.R.

REFERENCES

1. Radiofrequency Radiation Levels and Population Exposure in Urban Areas of the Eastern United States, EPA Report 520/2-77-008, May, 1978.

2. R. A. Tell et al., "Measurements of Radiofrequency Field Intensity in Buildings with Close Proximity to Broadcast Stations," Report ORP/EAD-78-3, August, 1978.

3. Private communication, Ron Peterson, Bell Telephone Laboratories.

4. R. A. Tell, An Analysis of Radar Exposure in the San Francisco Area, EPA Report ORP/EAD-77-3, March, 1977.

FIGURE CAPTIONS

1. A Plane Monochromatic Electromagnetic Wave.

2. A Plane Wave Incident on a Lossy Dielectric Material.

3. The Electromagnetic Spectrum in the Region of Non-Ionizing Radiation. This region can be divided into five regions in order of increasing frequency (1) Static; (2) Quasistatic; (3) Microwave; (4) Quasioptical (Nanowave); and (5) Optical.

4. Dependence on Frequency of Penetration Capability of Non-Ionizing Radiation in Man (15 cm. Minimum Dimension). Ordinate is ratio of electric field in center of body to incident (external) electric field.

5. Schematic Depiction of the Variety of Radiating Antennas, Ranging from Isotropic (d) to High Gain (a).

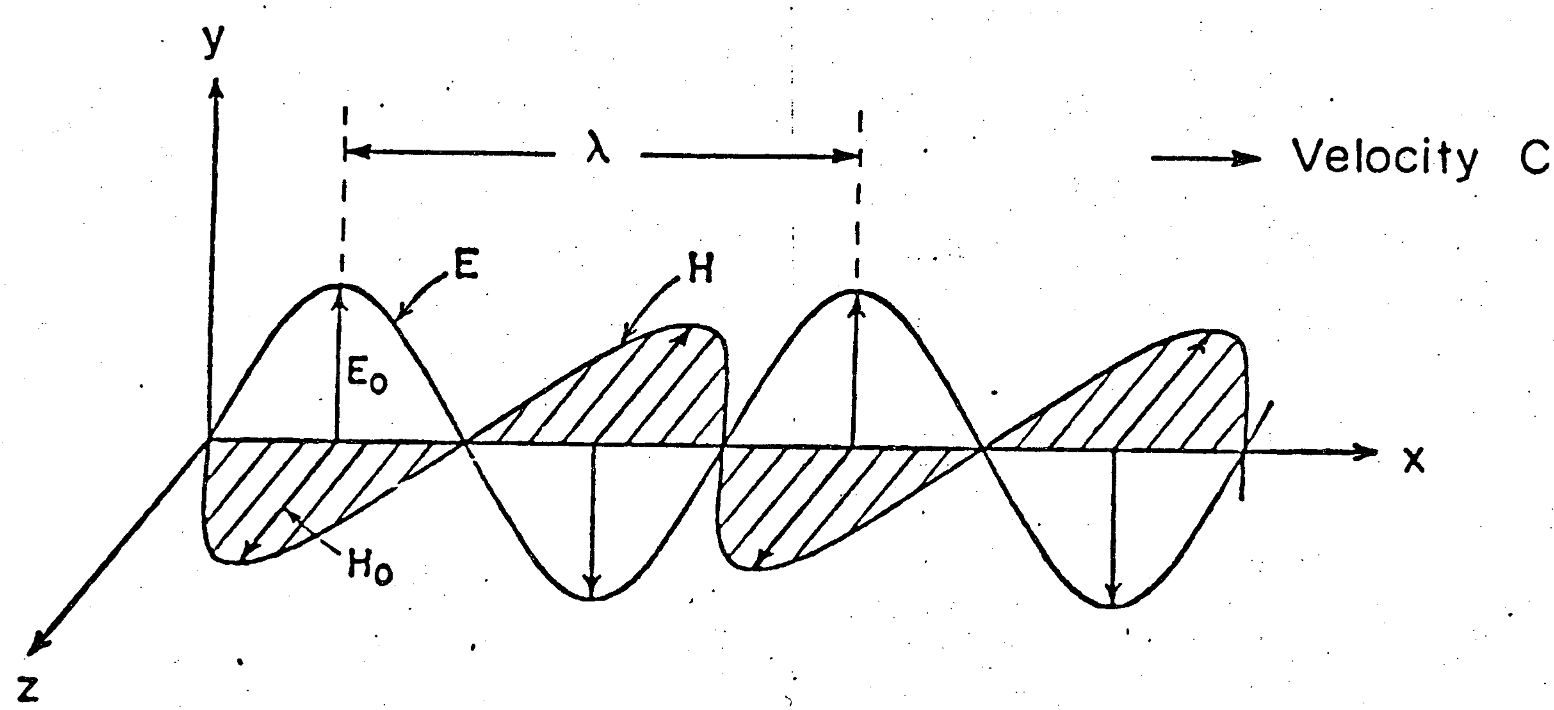
6. Spatial Dependence of Leakage Power Density for a Range of Radiated Power.

7. Relationship of Radiated Power Density to Total Radiated Power and Area of Radiated Beam.

8. A Map of "Intensity" Benchmarks Across the Non-Ionizing Radiation Spectrum.

9. An Exposure Diagram: Maximum Potential Exposure Near Microwave Oven Complying with U.S. Emission Standard is Compared with Exposure Standards of U.S. and U.S.S.R.

10. Average SAR for Average Man for an Incident Power Density of 1 mW/cm^2.



A Plane Monochromatic Electromagnetic Wave.

FIGURE 1

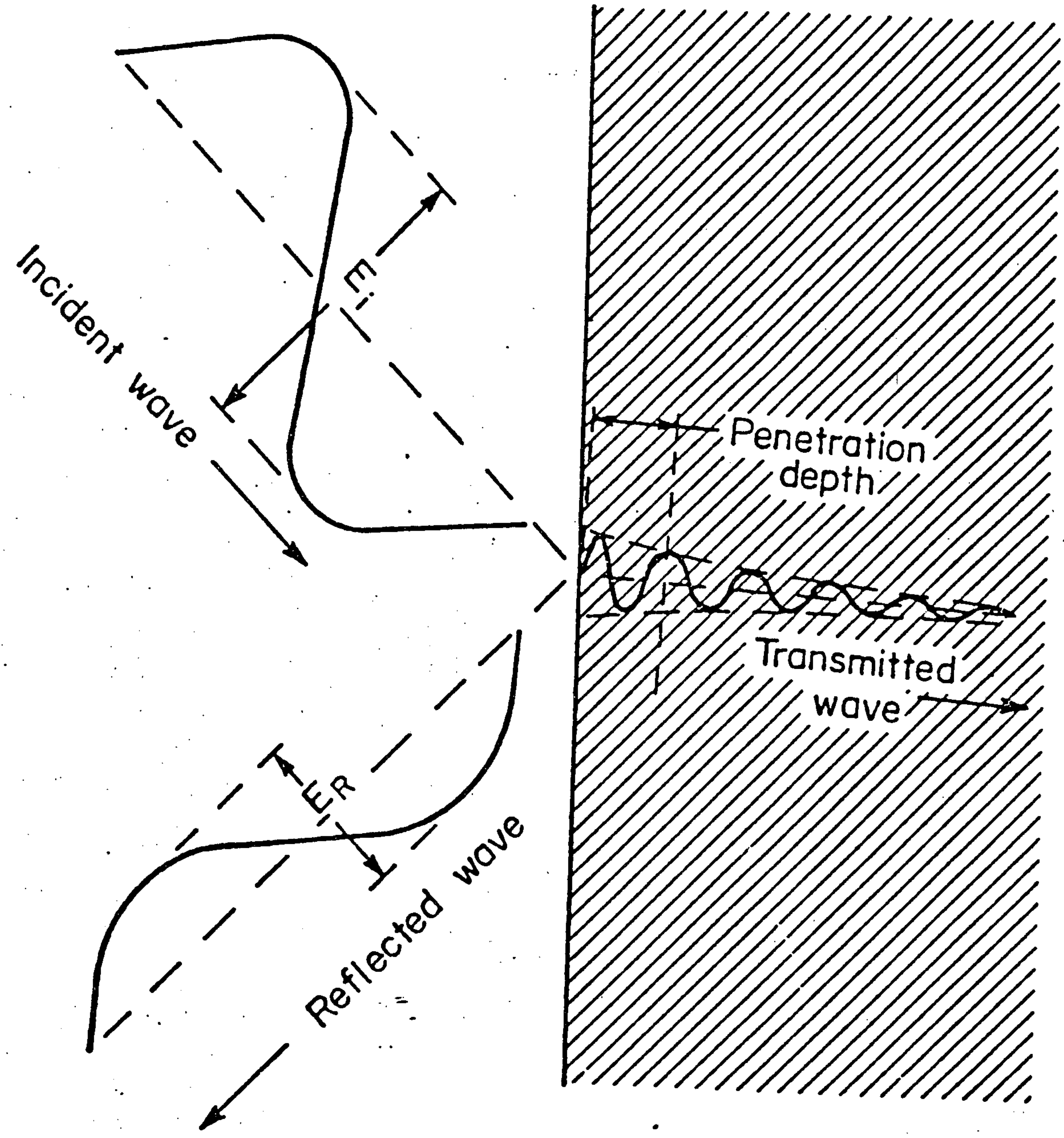
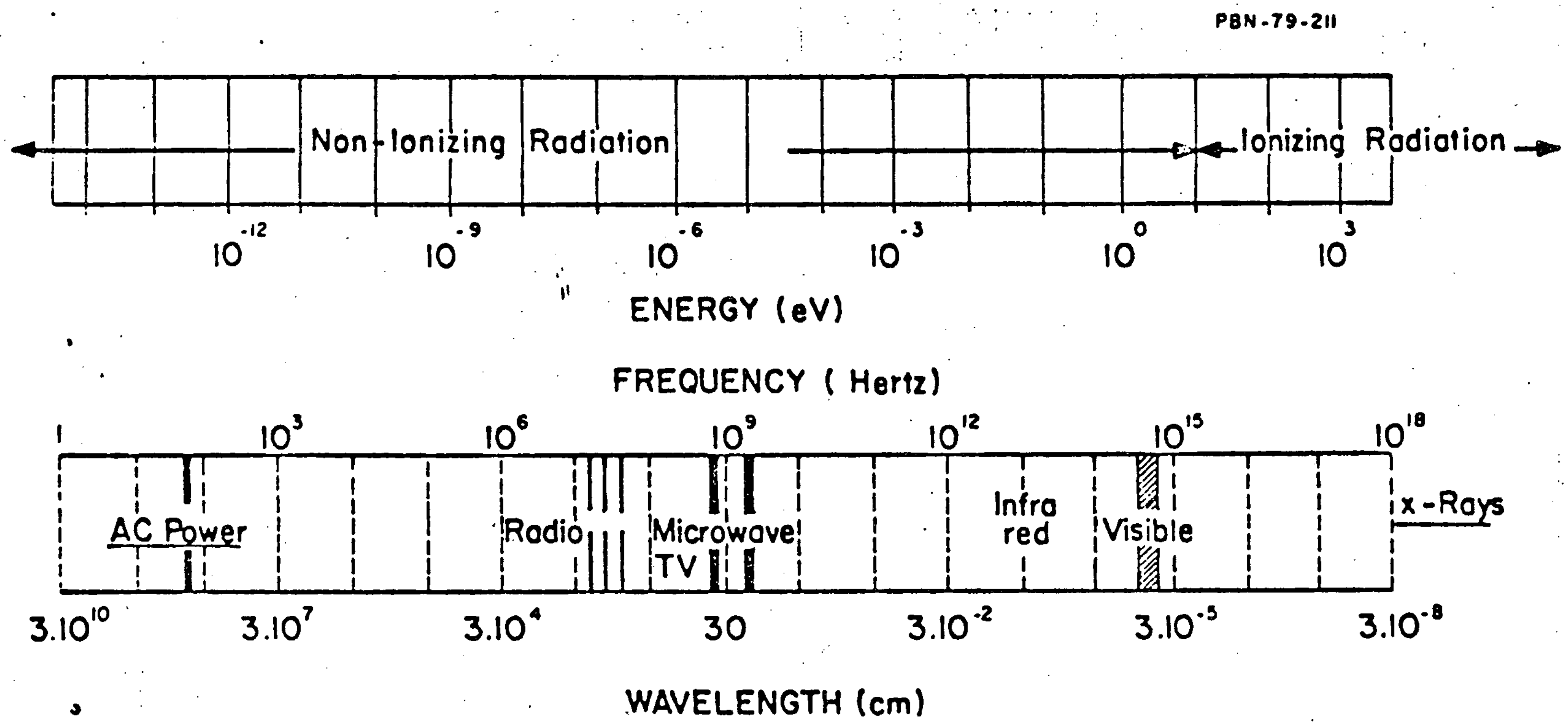

Incident wave
Ei
Penetration depth
Transmitted wave
ER
Reflected wave

FIGURE 2



The Electromagnetic Spectrum

FIGURE 3

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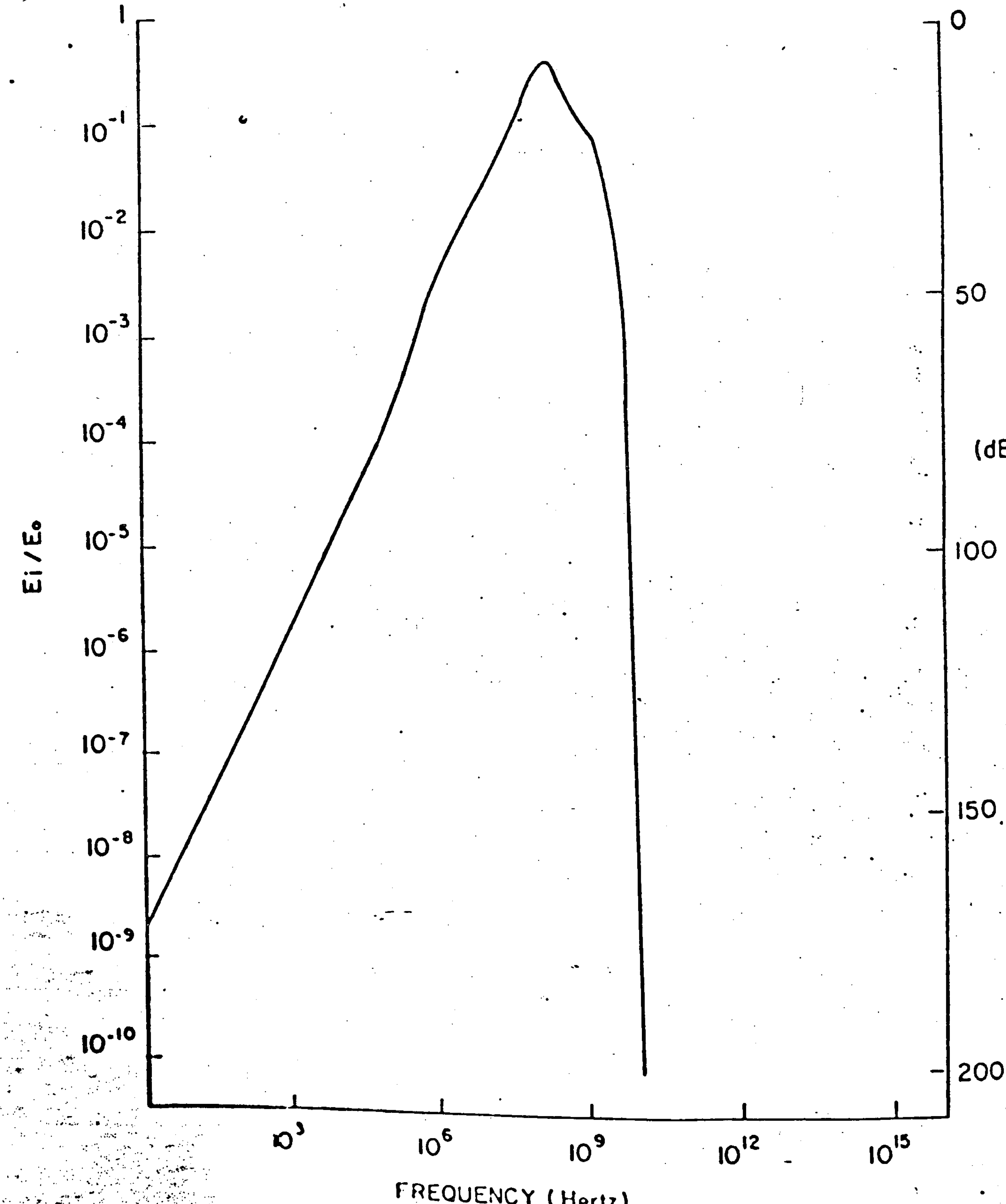
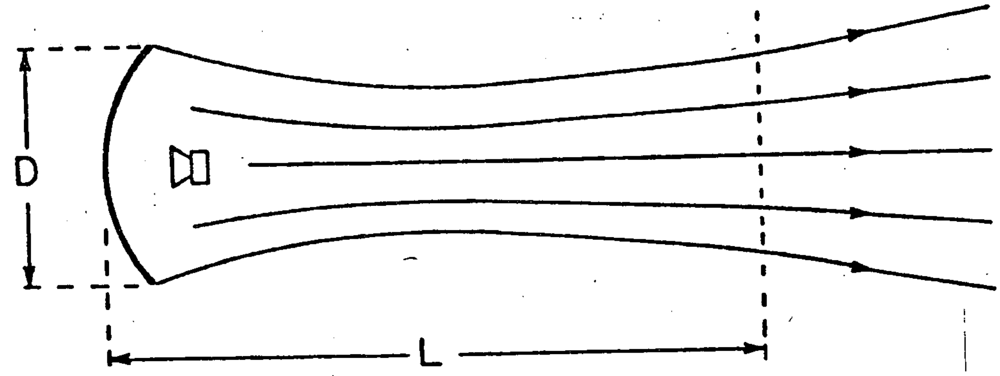
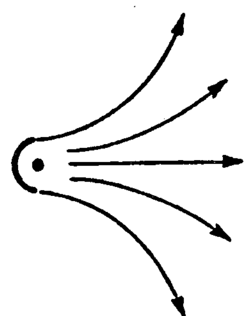


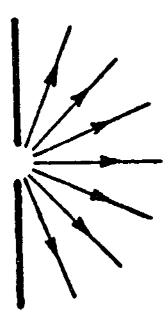
FIGURE 4



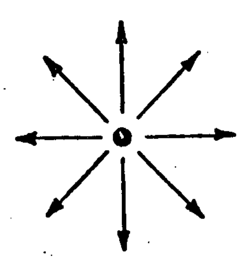
a) Large aperture antenna



b) Small aperture antenna or "applicator"



c) Very small radiation source or leakage source



d) Small isotropic radiation source

FIGURE 5

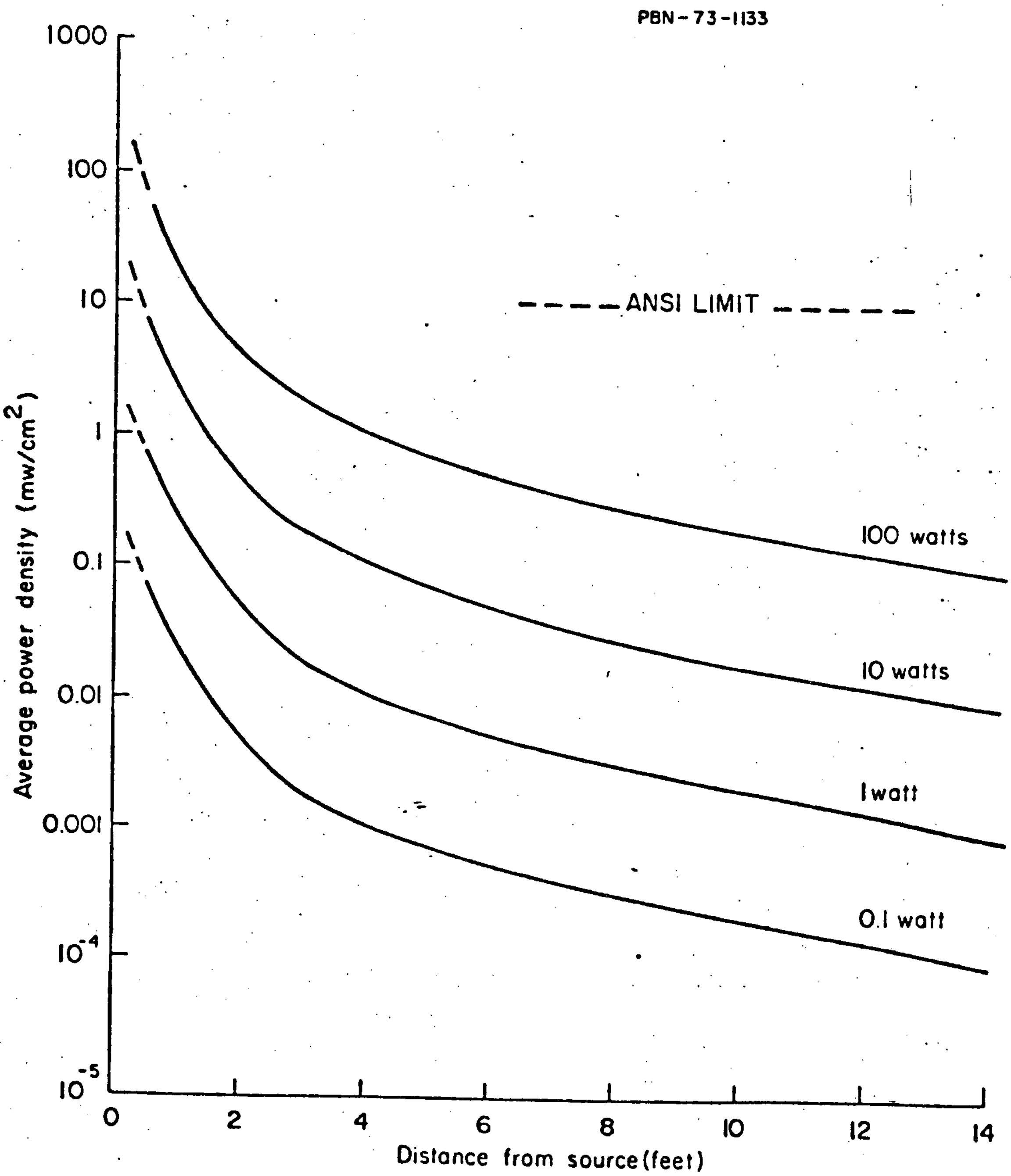

PBN-73-1133
1000
100
10
1
0.1
0.01
0.001
10-4
10-5
Average power density (mw/cm2)
ANSI LIMIT
100 watts
10 watts
1 watt
0.1 watt
0
2
4
6
8
10
12
14
Distance from source (feet)

FIGURE 6

PBN-73-1239

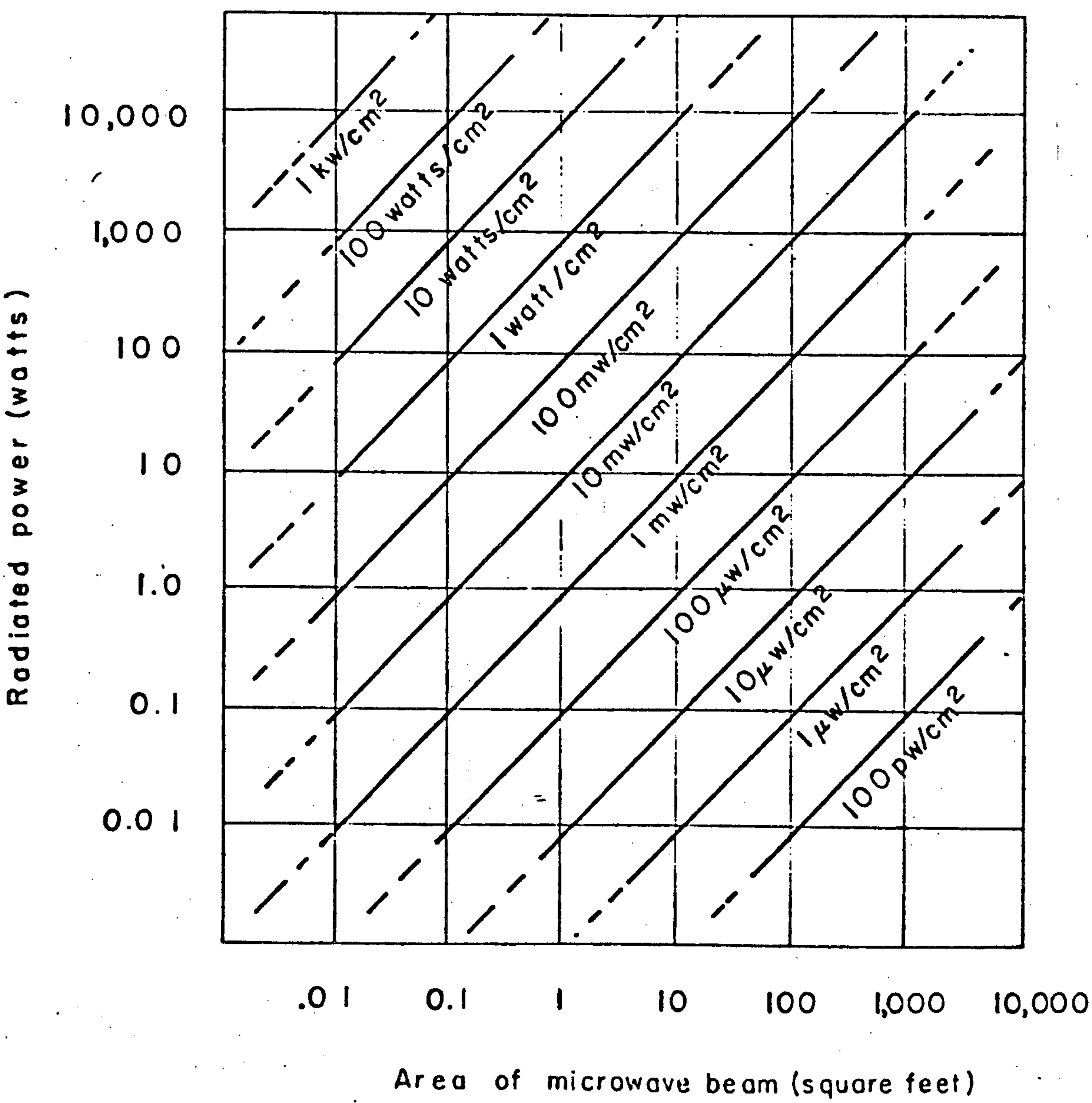
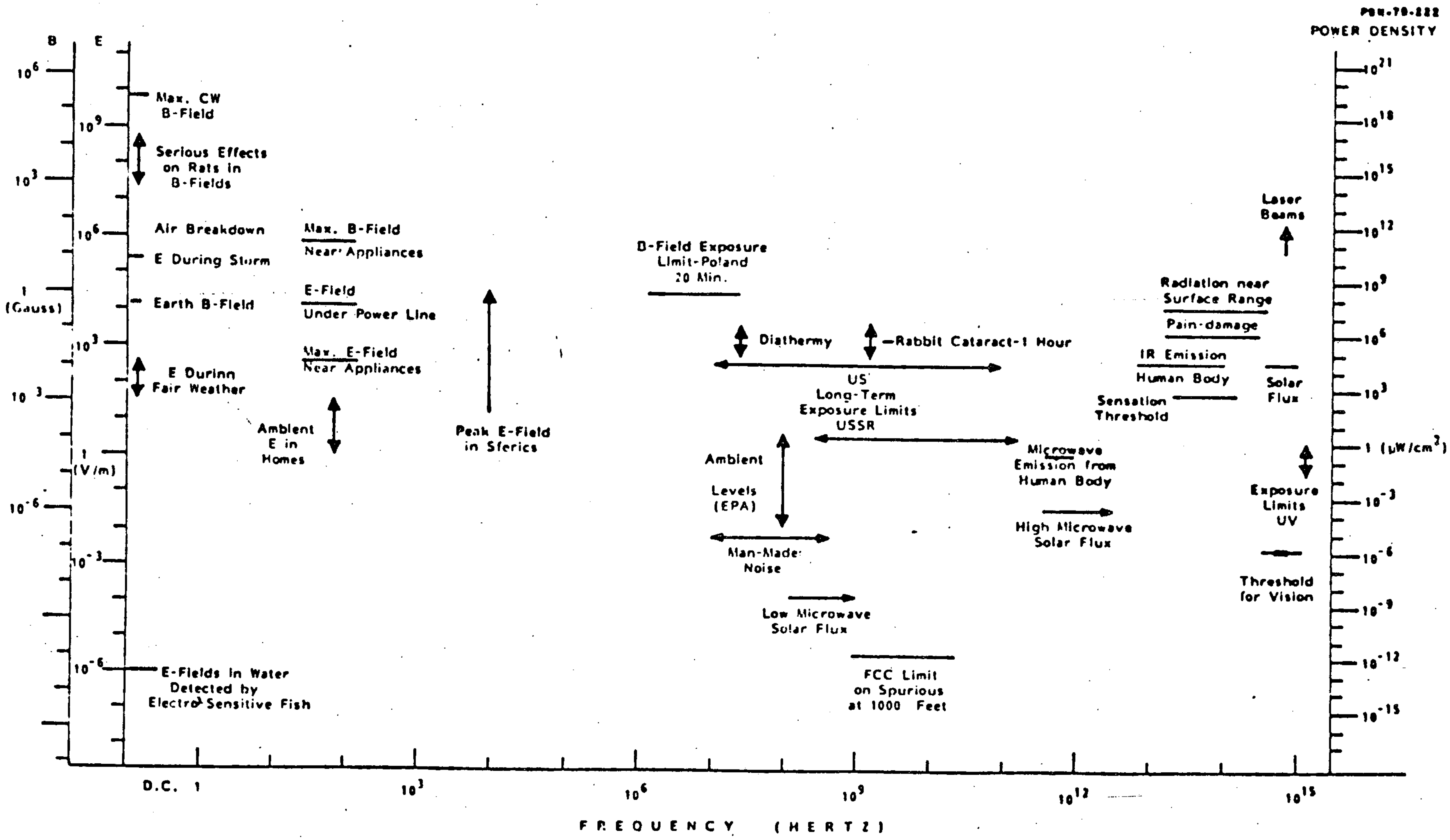


FIGURE 7



PSN-79-222
POWER DENSITY
B
E
Max. CW B-Field
Serious Effects on Rats in B-Fields
Air Breakdown
E During Storm
Earth B-Field
E During Fair Weather
Max. B-Field Near Appliances
E-Field Under Power Line
Max. E-Field Near Appliances
Ambient E in Homes
Peak E-Field in Sferics
B-Field Exposure Limit-Poland 20 Min.
Diathermy
Rabbit Cataract-1 Hour
US Long-Term Exposure Limits USSR
Ambient Levels (EPA)
Man-Made Noise
Low Microwave Solar Flux
FCC Limit on Spurious at 1000 Feet
Microwave Emission from Human Body
High Microwave Solar Flux
Radiation near Surface Range
Pain-damage
IR Emission Human Body
Sensation Threshold
Laser Beams
Solar Flux
Exposure Limits UV
Threshold for Vision
E-Fields in Water Detected by Electro Sensitive Fish
1 (Gauss)
1 (V/m)
1 (μW/cm²)
D.C. 1
FREQUENCY (HERTZ)

FIGURE 8

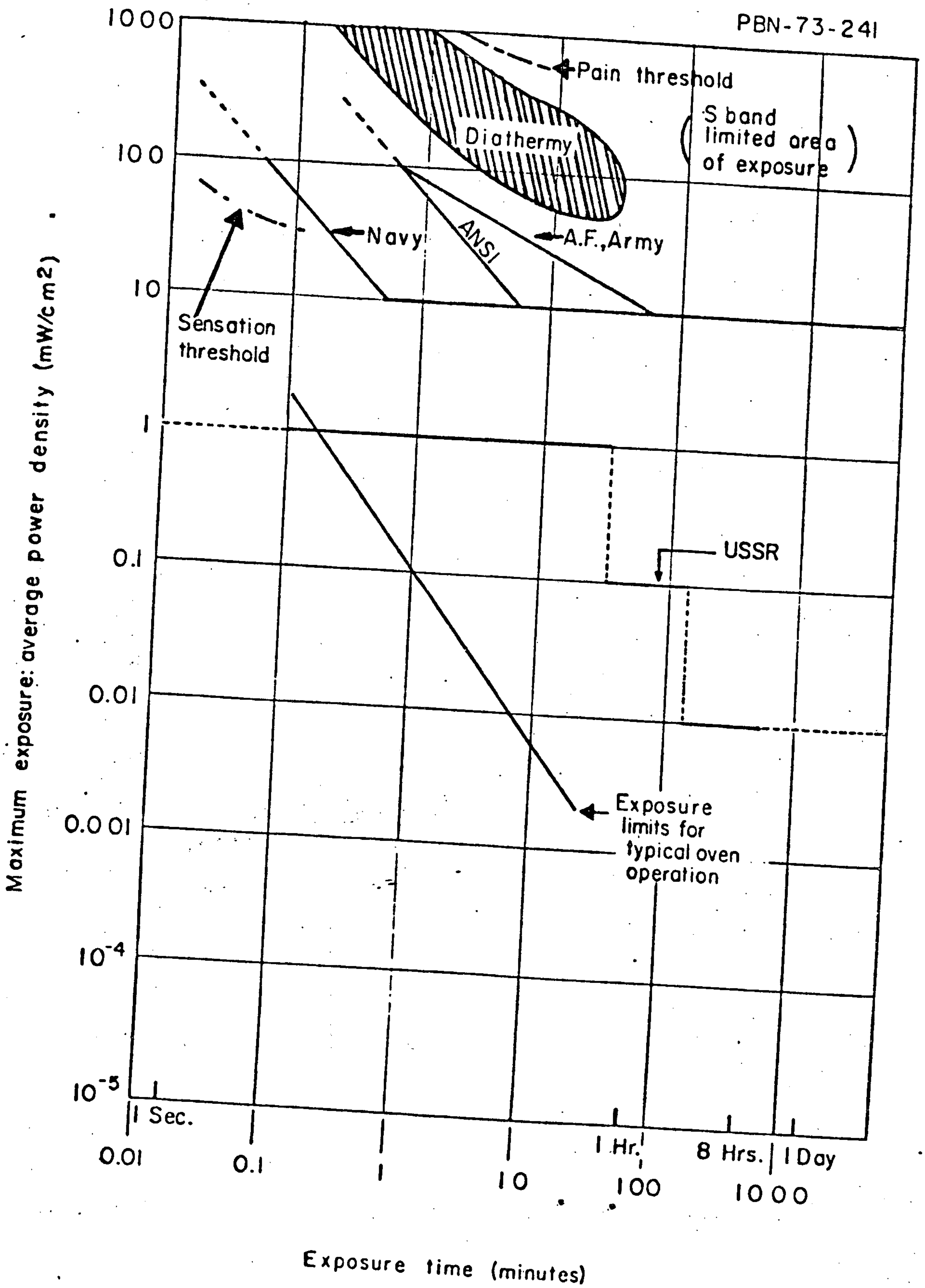

PBN-73-241
Pain threshold
S band limited area of exposure
Diathermy
Navy
ANSI
A.F., Army
Sensation threshold
USSR
Exposure limits for typical oven operation
Maximum exposure: average power density (mW/cm2)
1000
100
10
1
0.1
0.01
0.001
10-4
10-5
1 Sec.
1 Hr.
8 Hrs.
1 Day
0.01
0.1
1
10
100
1000
Exposure time (minutes)

FIGURE 9.

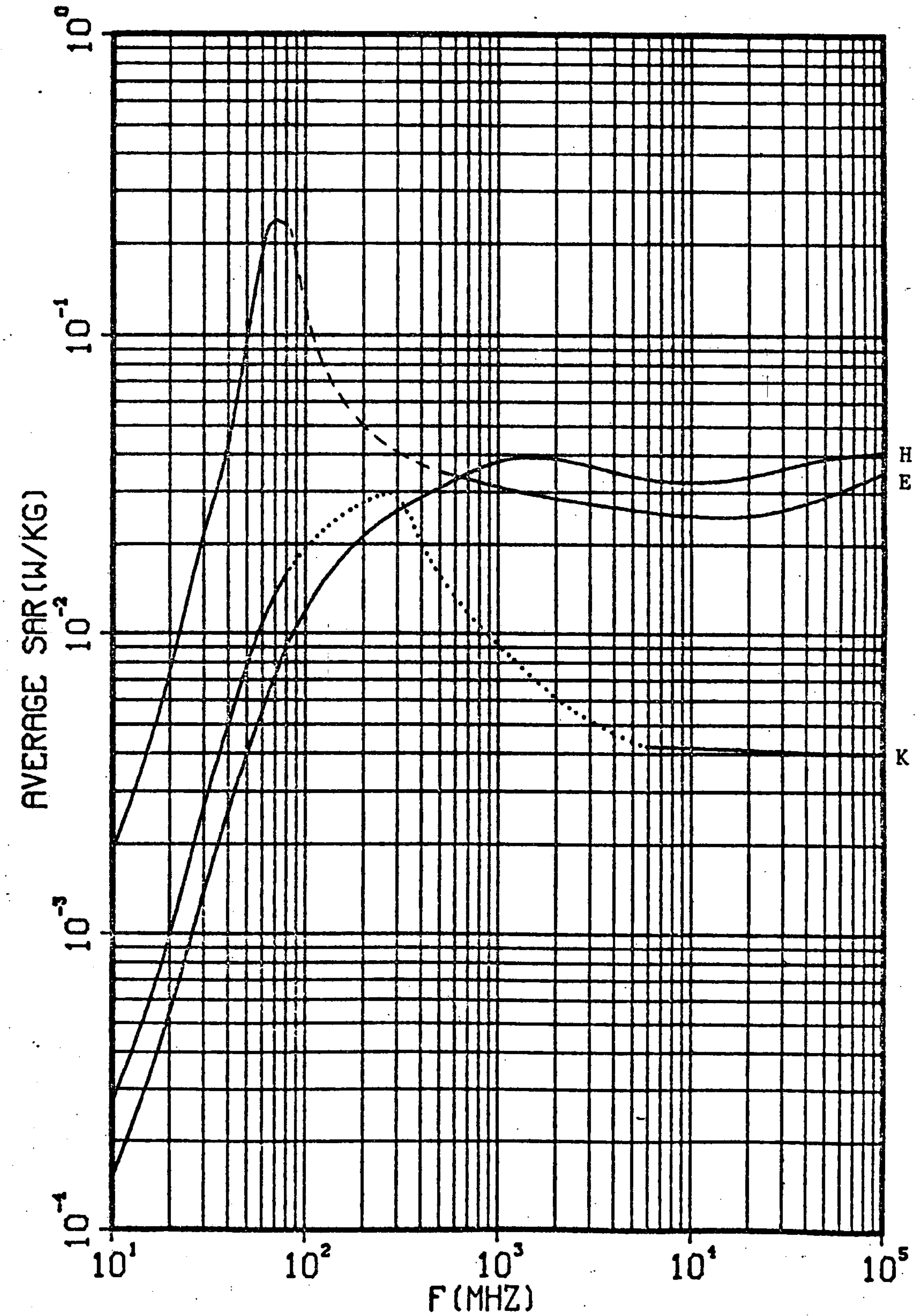

AVERAGE SAR(W/KG)
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
F(MHZ)
H
E
K

FIGURE 10