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The Subcommittee on Public Health Aspects of Energy of the Committee on Public Health of the New York Academy of Medicine

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WILLIAM D. SHARPE, M.D., ***Editor***

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SYMPOSIUM ON HEALTH ASPECTS OF NONIONIZING RADIATION

APRIL 9 AND 10, 1979

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*A paper presented by William M. Leach, Ph.D. will appear in a subsequent issue and one presented by Edward L. Hunt was not submitted for publication.

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BULLETIN OF
THE NEW YORK ACADEMY
OF MEDICINE

VOL. 55, NO. 11 DECEMBER 1979

OPENING REMARKS*

NORMAN SIMON, M.D.

Chairman
Subcommittee on Public Health Aspects of Energy
The New York Academy of Medicine

Clinical Professor of Radiotherapy for Environmental Medicine
The Mount Sinai School of Medicine of the City University of New York
New York, New York

THIS is the second of a series of conferences on energy sponsored by the Committee on Public Health of the New York Academy of Medicine. The biological effects of modern energy sources have become important factors in decisions which affect the very nature of our society. Environmental pollution by sulfur oxides and particulates was considered by this committee in a conference on March 23 and 24, 1978, and published proceedings of this conference are available.

Conferences on the biological effects of auto emissions, coal, oil, and nuclear energy are in planning stages by the New York Academy of Medicine. We organized these symposia to educate physicians on the state of the art of the biological effects of the various sources of energy. The subject of sulfur oxides was first because of urgent interest in revising standards for this noxious pollutant. By the time we had finished our

*Presented as part of a *Symposium on Health Aspects of Nonionizing Radiation* sponsored by the Subcommittee on Public Health Aspects of Energy of the Committee on Public Health of the New York Academy of Medicine and held at the Academy April 9 and 10, 1979.

symposium, evidence of the hazard to New York City of its sulfur oxides levels was less certain and, indeed, we dug deep to show significant biological effects of ambient levels of these noxious agents.

We fortunately had Dr. Herbert Pollack, advisor to the State Department, at that meeting, and he brought to the attention of our Subcommittee on the Public Health Aspects of Energy the importance of a meeting on the biological effects of microwave radiation. We accepted the challenge to develop a symposium on the subject, and are grateful to him for spearheading the selection of our program committee, our speakers, and our audience.

Had we been prescient enough to realize how involved we all are today in the Three Mile Island reactor accident we might have regarded the hazards of ionizing radiation as a more urgent topic. However, perhaps it is all for the good that we now focus on the temporarily less sensationalized problem of nonionizing radiation so that our deliberations need not be hurried or influenced by the frenzy of the media, as now evident at the site of the reactor accident.

Microwaves are now an urgent issue because of basic conflicts concerning appropriate standards for exposure of the public. We are in a biosphere bathed in ionizing radiation—cosmic, terrestrial, and man-made. We are also now bathed in microwaves and radiowaves from radar, television, citizen band radios, and even from the kitchen. The all-pervasive radiofrequency and microwave beam on adobe huts along the Nile and penthouses beside the Empire State building, on the beach at Cape Cod, and the embassy in Moscow, on short-order cooks and long-distance pilots, on radio hams and highway cops, on cancer patients and charlie horses. And there are imaginative projects which would involve microwave transmission of solar energy to the earth. Further, some surveillance uses of microwaves have been cloaked in secrecy, and it is hoped that we will obtain some insight into their significance.

Is there significant biological effect from such radiation? The sources of microwave radiation, their measurement, and their biological effects are not clearly understood by the lay public, and certainly not sufficiently by physicians. A patient asks for the advice of a doctor, and this conference is aimed at providing the physician with the state-of-the-art knowledge in the field. It is fitting that such an issue as the biological effects of microwave radiation be presented to physicians. Physicians are used to considering benefits and risks as they prescribe and advise treatment for their patients.

At times such decisions are based on less than ideal information, but conflicting viewpoints must be evaluated when medical action is required. Similarly, the public must decide on issues concerning benefits and risks of energy sources. As an example, there is little doubt that coal would be our unquestioned substitute for oil if there were not the risks of pollution, hazards of mining, and disadvantages to the environment as risk factors.

As we develop a society in which we have more television sets than bathtubs, and this year more microwave ovens are sold than conventional ranges, the questions and problems concerning the safety of nonionizing radiation naturally proliferate. Concerning the effects of microwave radiation, there is no doubt that, at doses sufficient to create heat in the human body, definite biological changes occur. But what about the amount of microwave radiation below the level of creating heat? Are there significant nonthermal effects? This is a poignant question whose answer and comments will be of great interest.

The Subcommittee on Public Health Aspects of Energy of the Committee on Public Health of the New York Academy of Medicine is indebted to its Program Committee on microwaves, and special thanks are extended to its memebers: Dr. Merril Eisenbud, H. Janet Healer, Dr. John M. Osepchuk, Dr. Herbert Pollack, Dr. Leonard Solon, and George M. Wilkening.

SOURCES AND BASIC CHARACTERISTICS OF MICROWAVE/RF RADIATION*

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THE late Professor Curtis C. Johnson had considerable insight into what was required for research on the bioeffects of nonionizing radiation, particularly in the "microwave/RF" range.[1] His approach required interdisciplinary cooperation and communication. Ten years ago a number of physicians[2] asked for help in understanding the physics and engineering aspects of microwaves, recognizing that their "physicist colleagues are in the same position with regard to biology." It is essential to understand certain physical concepts and terms if a rational view of this subject is to be developed. It is also important to have some idea of how the physical quantities are expressed quantitatively, how they are calculated, and some of the "benchmarks" in both the natural and man-made environments that give some meaning to quantitative levels of fields or radiation.

The physicians mentioned earlier pointed out that they were familiar with ultraviolet, infrared, and ionizing radiations, but did not understand how microwave bioeffects occur. Understanding of all nonionizing radiation is based on the concept of an electromagnetic wave which describes how electric and magnetic forces or disturbances propagate or travel in space. The electric forces act on charges whereas the magnetic forces act on magnetic charges or poles. Everyday experience with static charge and magnets helps to provide some understanding of these basic electric and magnetic concepts.

Microwaves are a special type of electromagnetic waves or fields which in general includes some perhaps more familiar waves such as visible light, infrared, radio, and household electricity. All these types of energy radiate as waves as depicted in Figure 1. We show a wave "propagating" in the x

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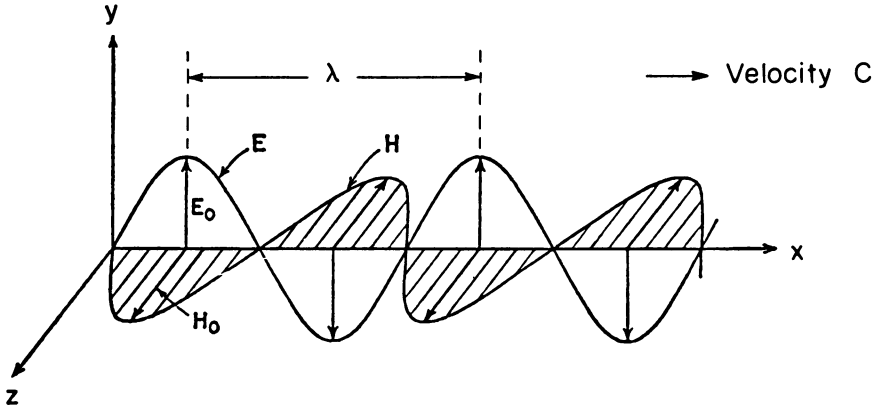

Fig. 1. A plane monochromatic electromagnetic wave

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 such as 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, we see not a steady field or force but one which alternates in direction at a rate called frequency.

Figure 1 also shows 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/sec. 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.

Because 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

$$f = \frac{c}{\lambda} \tag{1}$$

Material objects, including materials with charges, experience different results in being shaken at different rates or frequencies. Imagine a swing being pushed very slowly so that it moves with one, then pushing it in resonance with its natural motion, and then shaking it in cyclical fashion as fast as we can, e.g., three to four 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 shown in Figure 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's 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

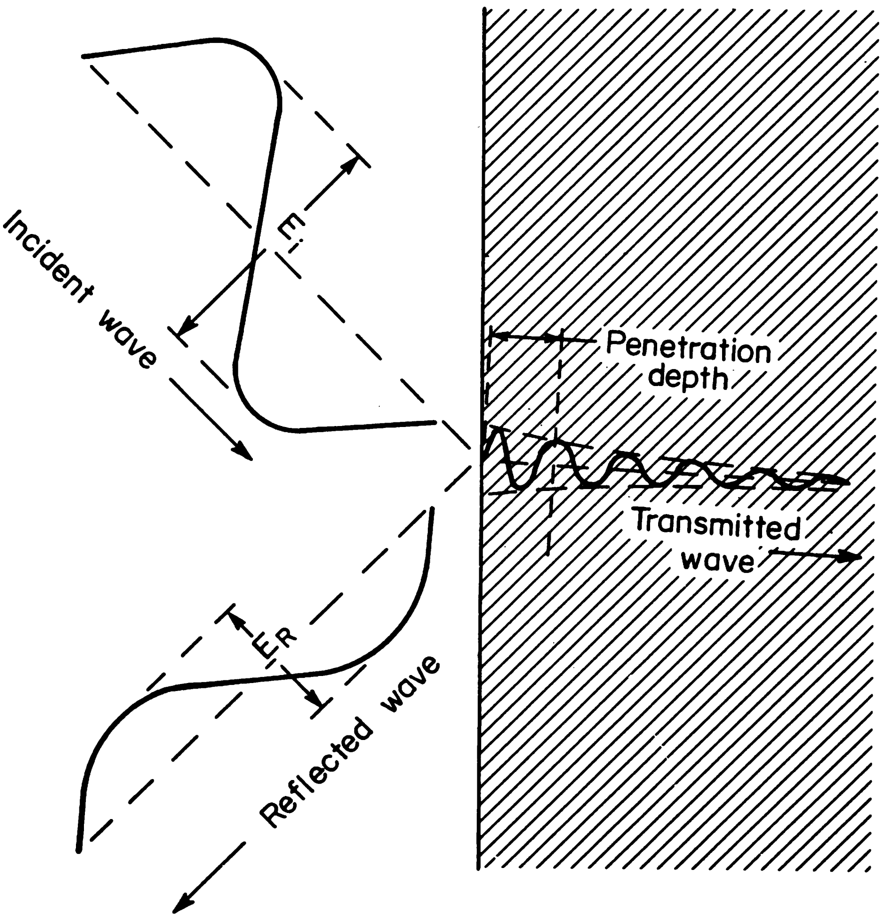

Fig. 2. A plane wave incident on a lossy dielectric material

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 degree of reflection and penetration for a particular material depends on its dielectric properties. Two basic characteristics describe the microwave properties for a particular material at a given frequency. These are dielectric constant (actually the so-called relative dielectric constant) ϵ and the so-called loss tangent tan δ. The dielectric constant ϵ tells us a lot about reflection properties and wavelength in the material. The latter is reduced from the free-space value λ_o by the factor $\sqrt{\epsilon}$, i.e.,

$$\lambda = \frac{\lambda_o}{\sqrt{\epsilon}} \tag{2}$$

For biological materials $\sqrt{\epsilon}$ is large, possibly as high as 9, so that wavelengths in biological tissue at 2,450 MHz. are small—i.e., if $\lambda_0 =$ 12.25 cm, $\lambda \sim 2$ cm.

If the wave in Figure 2 is normally incident (i.e., perpendicular to the material surface), the reflected power relative to the incident power is approximately given by

$$\frac{P_{reff}}{P_{inc}} = \left[\frac{1-\sqrt{\epsilon}}{1+\sqrt{\epsilon}}\right]^2 \tag{3}$$

and for biological tissue this can be as high as 60% reflection.

The loss tangent tan δ tells what the penetration depth D is for a given material by the formula

$$D = \frac{0.225 \quad \lambda_o}{\sqrt{\epsilon}\sqrt{\sqrt{1+\tan^2\delta}-1}}$$

or for small tan $\delta << 1$

$$D \approx \frac{0.318\ \lambda_o}{\sqrt{\epsilon}\tan\delta} \tag{5}$$

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 given by

$$\mathrm{SAR} = \frac{1}{2\rho}\omega\epsilon_0\,\epsilon\tan\delta\,E_{in}^2 \text{ watts/kg.} \tag{6}$$

A PARTIAL LIST OF DIELECTRIC PROPERTIES OF FOODS AND OTHER MATERIALS AT 2,450 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

where

SAR	is the power transferred to the absorber by the electric field in the body
ρ	is the mass density of the body, in kg./m.^{3}
ϵ_0	is the permittivity of free space, in farads/m.
ϵ	is the relative dielectric constant
tan δ	is the loss tangent
ω	is the radian frequency given by $\omega = 2\pi f$
E_{in}	is the electric field in volts/m. at the point in the body, with the subscript "in" to emphasize that the field inside the body is not the same as the field in the incident radiation. More explanation of E_{in} is given below.

Examples of various materials and their properties at the common microwave frequency of 2,450 MHz. are shown in the table. 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 Figure 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 equation (1) and either quantity by itself specifies the waves under discussion.)

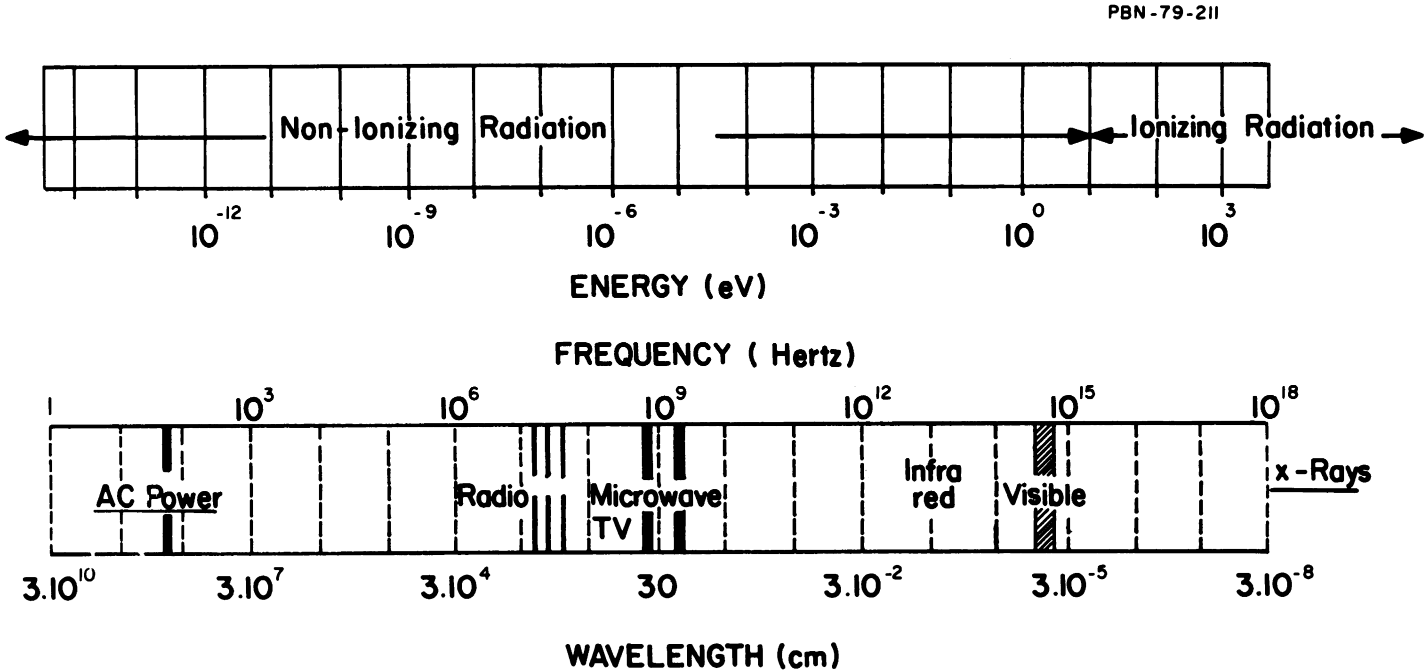

Fig. 3. The electromagnetic spectrum in the region of nonionizing radiation. This region can be divided into five regions in order of increasing frequency: 1) static, 2) quasistatic, 3) microwave, 4) quasioptical (nanowave), and 5) optical.

The table demonstrates that alternating current power, i.e., household electricity, is at 60 cycles per second or 60 Hz. 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) cm. or 5,000 km. At the other end of this part of the spectrum of interest to us is visible light. (This part is called nonionizing radiation.) At this end, optical frequencies of 10^{15} Hz. are difficult to conceive while the wavelength is a bit easier to appreciate, e.g., 1/100,000 of a centimeter or about 1/1,000 the diameter of a human hair.

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 (mW/cm.^{2}) are important in describing microwave effects.

In the microwave frequency range, optical effects such as 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. Microwave oven frequencies are at 915 MHz. and 2,450 MHz., two of the so-called ISM bands (industrial, scientific, and medical).

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 m. wavelength) to 100 GHz. (3 mm. wavelength) as the microwave range. It is expected that the heating, cooking, and biological effects of nonionizing radiation depend on the penetrating power of the radiation, and the latter is expected to peak in the microwave region as shown in Figure 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 as given by equations (4) and (5). Thus, internal field is large only in a finite range, which we can call microwave. This depends

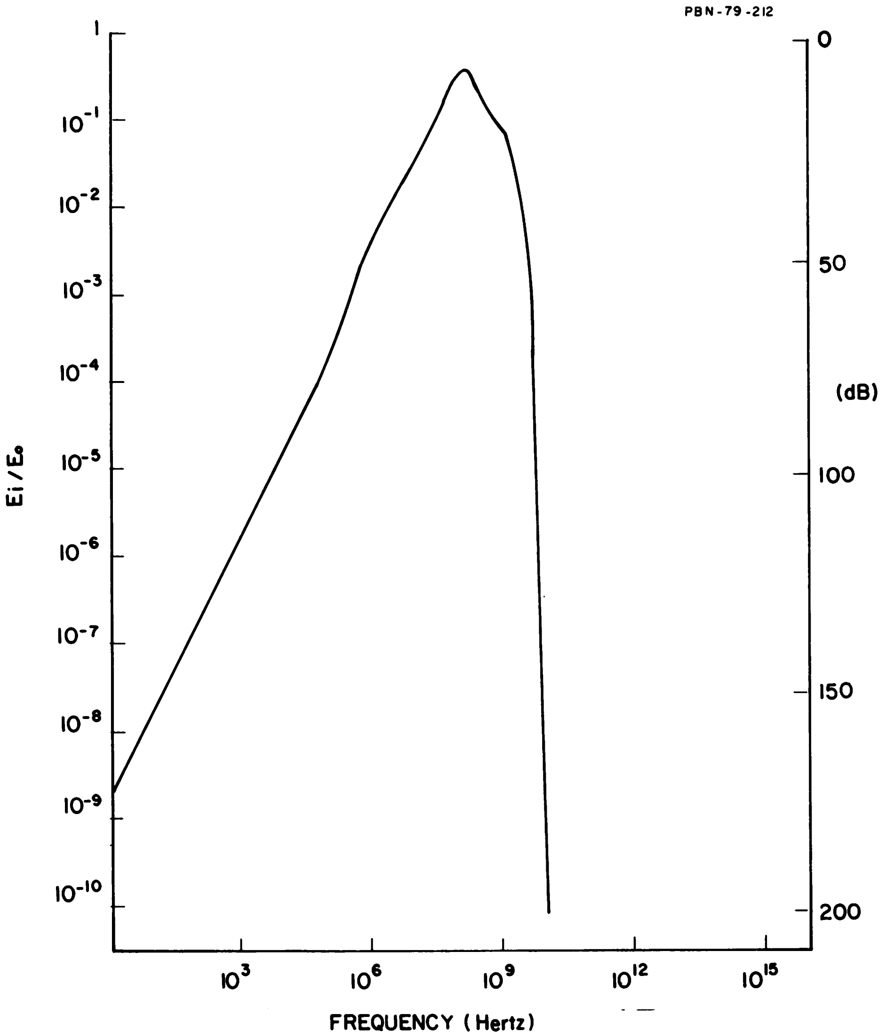

Fig. 4. Dependence on frequency of penetration capability of nonionizing radiation in man (15 cm. minimum dimension). Ordinate is ratio of electric field in center of body to incident (external) electric field.

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 nonionizing radiation, applies only in the far-field of some radiating source where there is a radiating plane-wave (Figure 1) with certain unambiguous relations between E and H fields and power flux or power density. In this case the power density is related to E field by

$$p_o(\text{W/m.}^2) = \frac{E^2\,(\text{V/m.})}{120\,\pi} \qquad (6)$$

or

$$p_o(\text{mW/cm.}^2) = \frac{E^2(\text{V/m.})}{4{,}000} \qquad (7)$$

The H field is also given by

$$H\,(\text{A/m.}) = \frac{E(\text{V/m.})}{120\,\pi} \qquad (8)$$

and the B field is given by

$$B(\text{gauss}) = \frac{E(\text{V/m.})}{30{,}000} \qquad (9)$$

At high frequencies, above microwaves, both the field concepts and power flux have value and an interrelation as given above. At low frequencies, however (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 relation exists between the E and H fields at any given point.

RELATION OF RADIATED POWER TO POWER FLUX

It is useful to review the relation 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 Figure 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

$$P_{rad} = 11.67\ R^2\, p_o \tag{10}$$

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/square centimeter (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 equation (11), i.e.,

$$P_{rad} = 5.84\ R^2\, p_o \tag{11}$$

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 Figure 6 for various radiated powers. At a distance of a few feet, powers over 100 W are required to produce power fluxes of $\sim$ 1 mW/cm.^{2}.

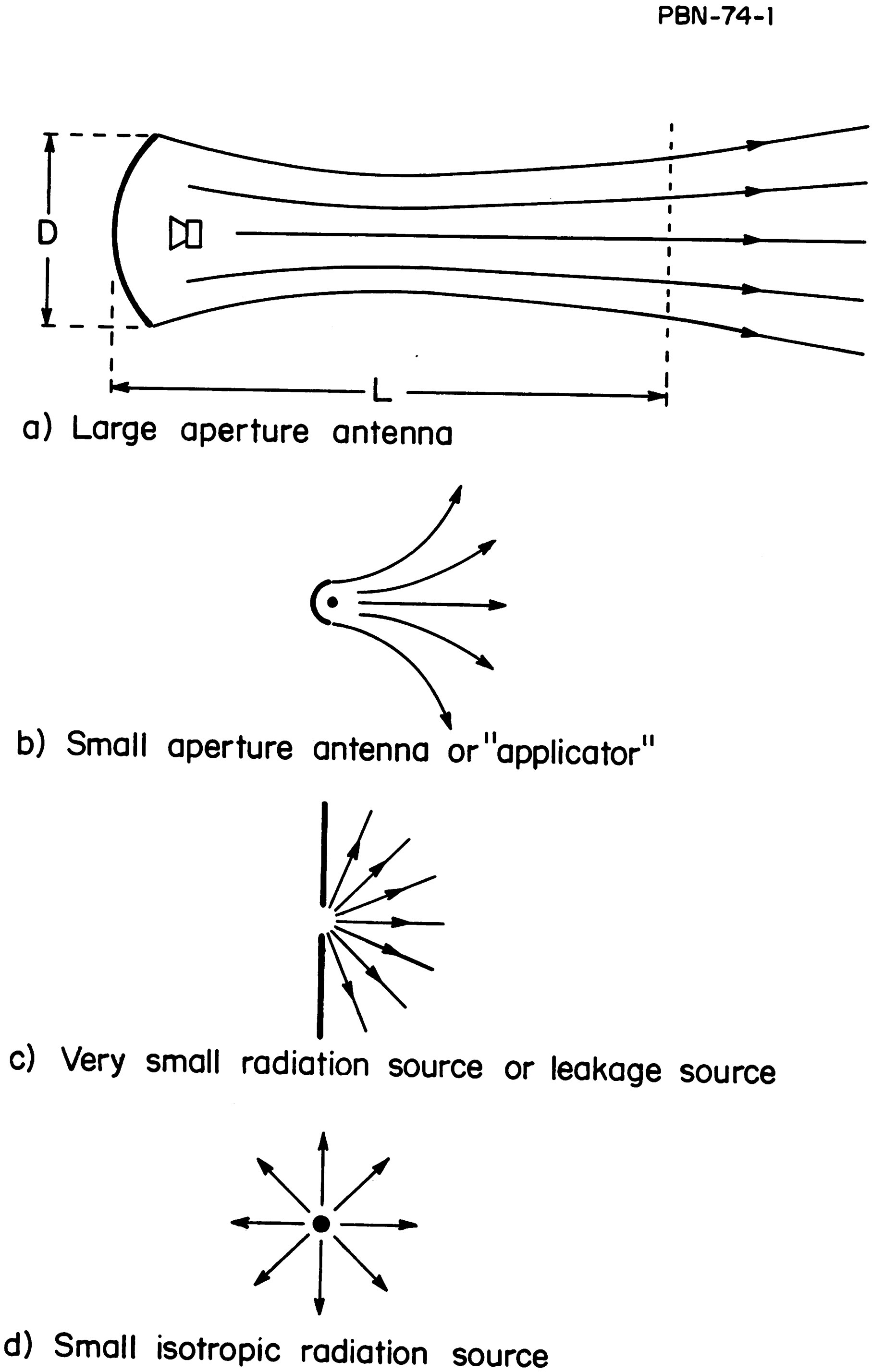

Fig. 5. Schematic depiction of the variety of radiating antennas, ranging from isotropic (d) to high gain (a)

Returning to Figure 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 (Figure 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 $L \sim D^2/2\lambda$. In the general case, the power density at distance R is

$$p_o = \frac{G\, P_{rad}}{11.67\, R^2} = \frac{(ERP)}{11.67\, R^2} \tag{12}$$

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

$$G = \frac{4\pi\, A_e}{\lambda^2} \tag{13}$$

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 1,000 (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 1,000 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 Figure 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 0.01 W 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 kw. must be radiated. Significant heating levels over an area of the

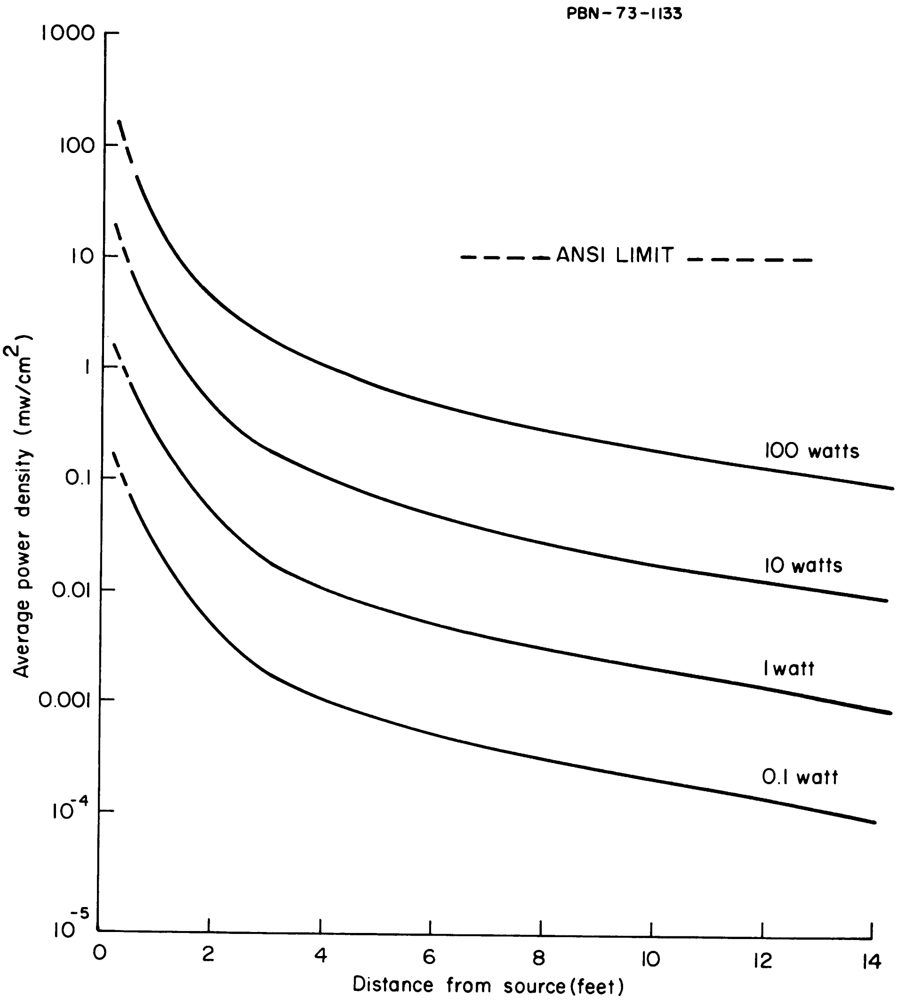

Fig. 6. Spatial dependence of leakage power density for a range of radiated power

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 Figure 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

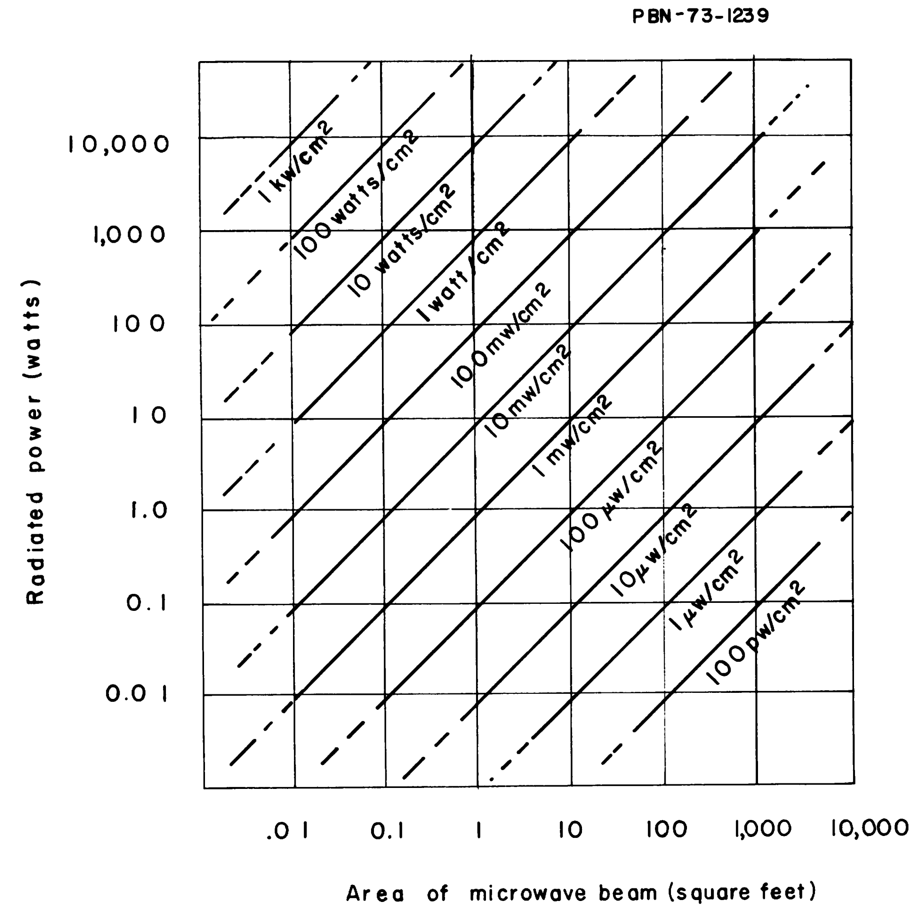

Fig. 7. Relation of radiated power density to total radiated power and area of radiated beam

one reason why early investigators saw more potential hazard in microwaves than lower frequencies which could not be so focused or directed.

Microwave Power Generators

The present state of the art in generation of microwave power is shown in Figure 8. Gridded tubes—bigger glass and ceramic envelopes but similar in appearance to receiving tubes—generate high powers up to

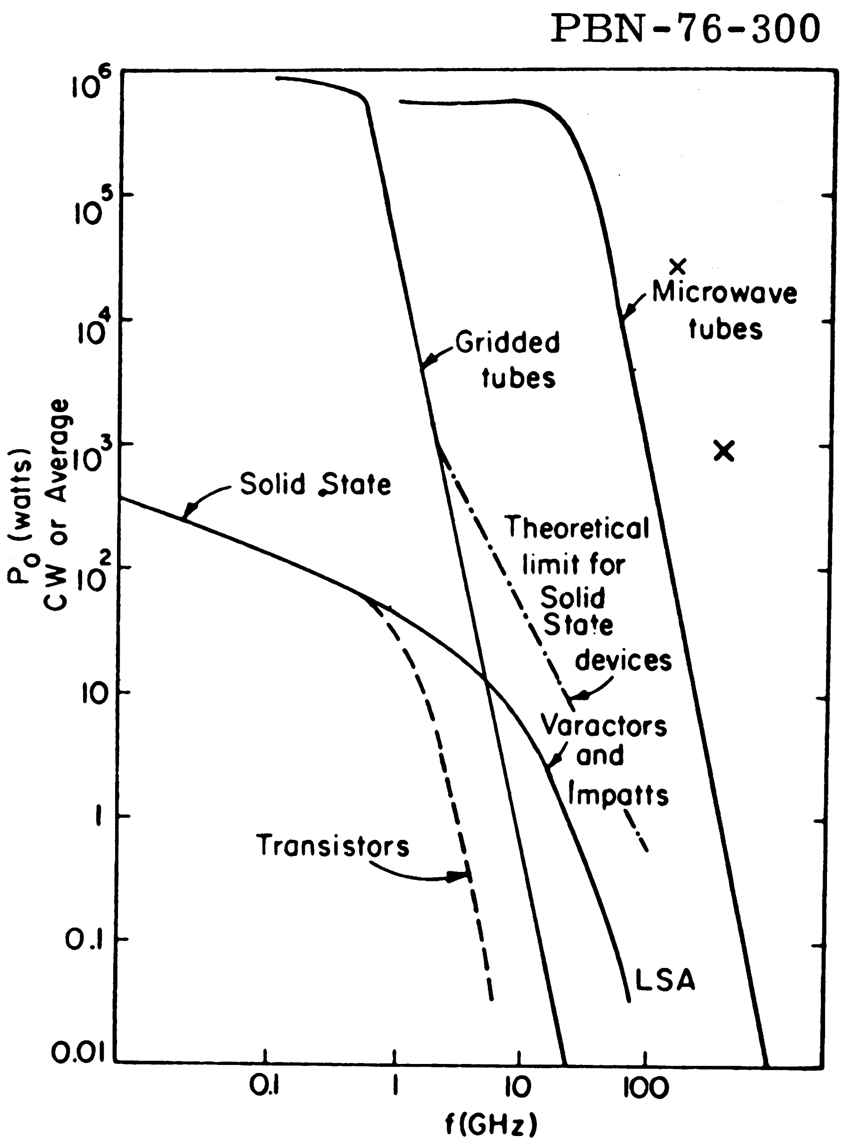

Fig. 8. Maximum limits of average output power from various microwave power sources (~ 1975)

1 MW at UHF frequencies and below. Lower powers are now generated with solid-state devices efficiently below UHF frequencies. Above UHF, efficient power generation is possible with a variety of "microwave" tubes up to 1 MW and 10 GHz. Both gridded tubes and microwave tubes[3] follow a high-frequency power limit which varies as f^{-5}. In recent years Soviet tube scientists have demonstrated[4] a breakthrough in generation of power at millimeter-wave frequencies as denoted by the crosses in Figure 8. These data are achieved with cyclotron-resonance tubes (gyrotrons) and are the basis for predicting future activity and serious applications of frequencies between 30 and 300 GHz.—the millimeter-wave band which has been slow in developing.

One thing to be considered when working near microwave tubes is the possibility of incidental x-ray generation because many tubes, e.g., radar transmitters, operate at peak voltages up to 100 kv. Even at tube voltages below 30 kv., significant x-radiation is possible because of the complicated interactions.

An x-ray tube consists of a source of electrons, a cathode, and a rotating anode which, when bombarded by high-voltage electrons, is the source of x rays. These same elements exist to some extent in any microwave tube except that the more massive tube bodies and perhaps additional shielding reduce the x ray level.

An example of a high-voltage tube, a traveling-wave tube for a high-power phased-array radar, operates at peak voltages ~ 50 kv. or more.

The variety of microwave tubes in a modern military aircraft includes magnetrons for radar transmitters, low-power reflex Klystrons for receivers, backward-wave oscillators for ECM (jamming) and cathode-ray tube for radar display. The latter tube, though not a microwave tube, is similar to that used in every television set. In recent years the cathode-ray tube in video-data terminals has been widely rumored to be a source of significant nonionizing radiation, though no such radiation is generated.

Applications of Microwave/RF Power

The classical application of microwave/RF power is for broadcasting where actual powers of tens of kilowatts and ERPs up to megawatts are radiated and directed toward the homes in the radius of up to 50 miles from the antenna. A typical broadcast-antenna complex on a high tower includes the radiating antennas for a number of VHF and UHF TV stations as well as a few FM stations. The antennas are typically hundreds of feet above the ground, but they direct their radiation toward the horizon and have enough power for efficient broadcasting—a vertical antenna gain of 20 dB is typical.[5]

A typical wire-rig amateur radio antenna may radiate hundreds of watts at hf or VHF.

Thousands of microwave-relay towers employ a radiating source of about a watt at frequencies of a few GHz. Because the towers are typically about 80 to 100 feet high and the application per se involves highly directed beams, the radiation levels on the ground are many orders of magnitude below 1 mW/cm.^{2} and are biologically negligible.

A classical airport radar application may operate at about 3 GHz. and use magnetrons of up to a megawatt peak power and a kilowatt average power. Antenna gains of ~ 30 dB are typical of such radars. More modern long-range radars for special military application are typified by the phased-array radar operating at L-band with average power in the tens of kilowatts. Because radars are directed typically above the horizon, they produce less power density on the ground at average distances of miles from the antennas than do broadcast transmitters.

The area of power applications affords many new and still emerging examples. The most dramatic is that of the consumer microwave oven operating at 2,450 MHz. and ~ 300 to 700 W. Several million ovens are manufactured each year. The oven employs a magnetron as a source but, because its operating voltage is below 4 kv., there is no measurable x-radiation. A very successful industrial heating application is that of tempering of meat. Today meat products worth billions of dollars are efficiently processed with the aid of equipment that utilizes 50 kw. at 915 MHz. The largest industrial application so far is foundry core drying for the auto industry such as the 150 kw. unit (915 MHz.) installed in a Pontiac foundry. Despite the high powers in such applications, leakage levels are well below microwave oven regulatory limits, i.e., 5 mW/cm.^{2} at 5 cm. from external surfaces. Special precautions are taken to prevent tampering with input and output ports in conveyor systems.

In addition to these there are medical heating applications—diathermy at 27 MHz. and 2,450 MHz. at power up to 100 w. Experimental medical heating is under study for possible use in cancer therapy, i.e., hyperthermia.

Finally, the blue sky possibility of microwave power transmission is under investigation, and tens of kilowatts at 2,450 MHz. have been successfully transmitted several miles to a rectenna receiver array. It is conceivable that in the future power applications will grow but that communication by radiation may be supplemented by such alternative modes of transmission as fiber optics.

MEANS OF REDUCING EXPOSURE TO MICROWAVE/RF

Microwave/RF radiation essentially does not penetrate even the thinnest sheets of metal, e.g., household aluminum foil. Perforated sheets of metal or even wire fences can be effective (e.g., 40 to 50 dB reduction in transmission shields for the right frequency ranges). Techniques of screening and door seals are described in the literature.[6,7]

RELATION OF EMISSION TO EXPOSURE

The emission power density at 5 cm. from a leakage point decreases roughly as the inverse square law to produce much lower whole body exposure values. The distinction is important in cases of leakage as in microwave ovens. Studies show that typical exposure near microwave ovens will be limited as depicted in Figure 9. Thus, while the maximum leakage emission is 5 mW/cm.^{2}, maximum exposures are calculated to be well below exposure standards of Eastern Europe. Exposure standards are functions of exposure duration. Thus, charts such as Figure 9 are useful in comparing exposure history and exposure standards.

POTENTIALLY HAZARDOUS INTERFERENCE

It has been known for years that whereas biologically significant average power densities are believed to be $\sim$ 1 mW/cm.^{2} and higher, much lower radiation levels could interfere with electronic equipment because of the nonlinear detection of such radiation by modern semiconductor components. Older unshielded cardiac pacemakers potentially were susceptible down to levels of $\sim$ 1 μW/cm.^{2} under worst-case conditions, i.e., a radiation frequency of $\sim$ 500 MHz. and a pulse modulation which mimicked that of the heart electrical pulses. In recent years, however, newly developed pacemakers almost universally are not susceptible,[8] even at radiation levels close to those specified in exposure standards.

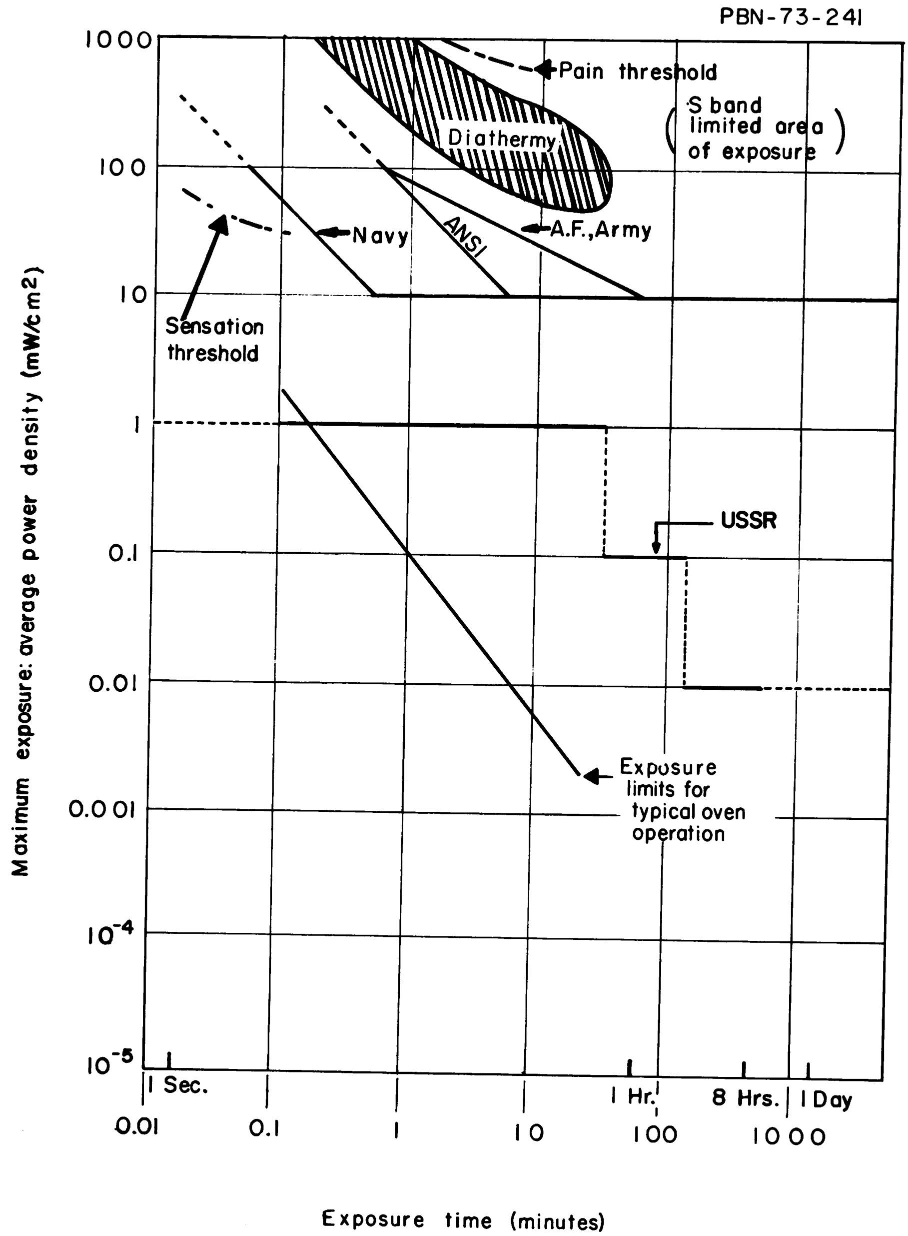

Fig. 9. An exposure diagram: maximum potential exposure near microwave oven complying with U.S. emission standard is compared with exposure standards of U.S. and U.S.S.R.

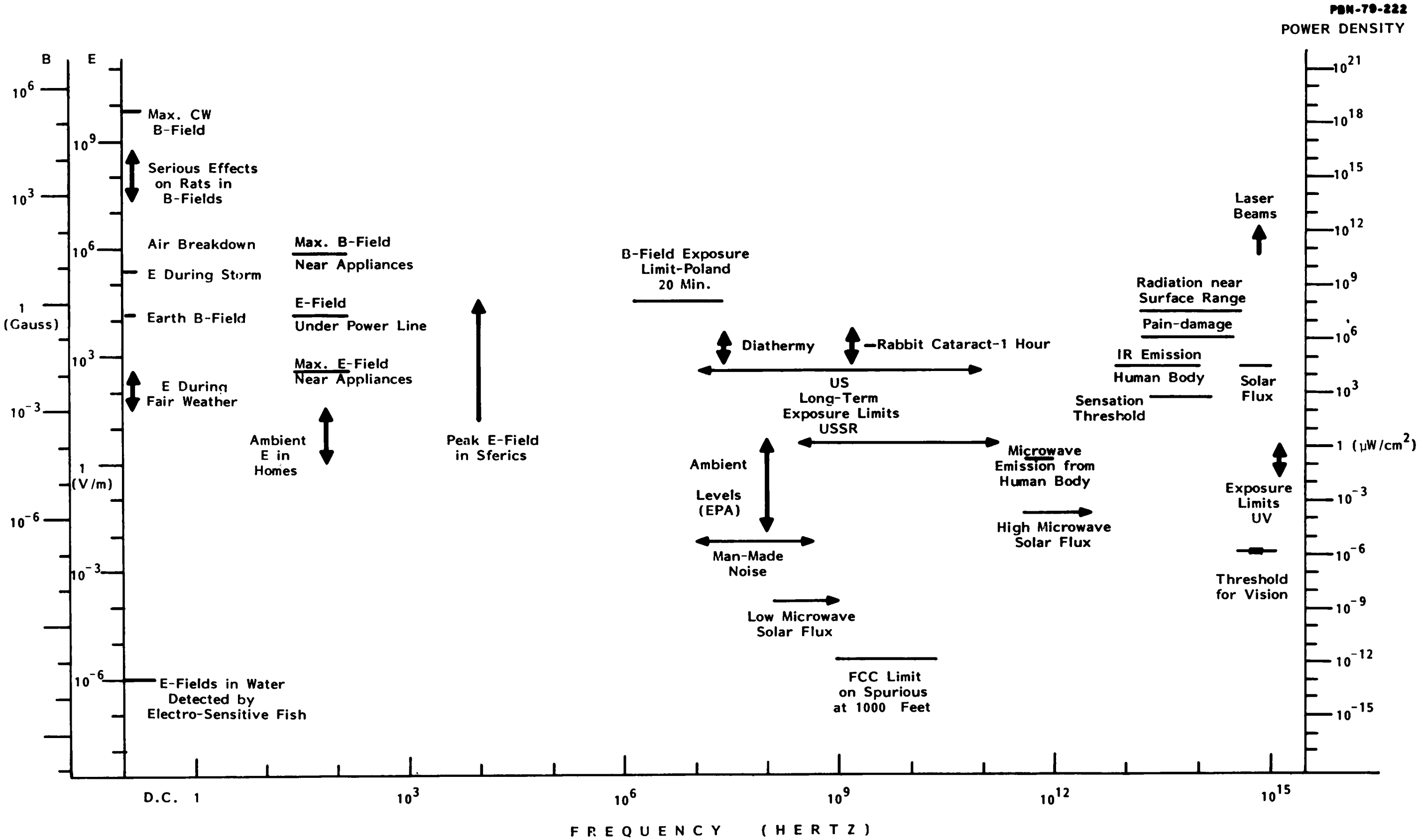

Fig. 10. A map of intensity benchmarks across the nonionizing radiation spectrum. The E and B scales are adjusted to correspond to the far-field values for radiation at power density shown on the right scale.

Comparison of Man-Made and Natural Levels of Nonionizing Radiation

In Figure 10 a map of intensity benchmarks is presented listing various levels of natural radiation. These are expressed in power density at the high end of the nonionizing radiation spectrum. At the low end of the spectrum, levels are expressed as E and B fields. The scale of fields is calibrated to agree with far-field relations 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. It is clear that man-made as well as natural radiation levels are quite high at both ends of the spectrum and low in the microwave range in the center.

The challenge to the research community is not only to discover significant biological hazards peculiar to the microwave range but also to discover beneficial applications, particularly for medical purposes, e.g., hyperthermia for cancer therapy. As the subject is explored, it is above all important to keep a rational perspective. Despite the uniquely man-made characteristics of microwave radiation, there is little evidence of serious harm to humans from exposures encountered during the last 30 years. One can, a priori, hope to find as many benefits as hazards not yet detected.

Summary

An adequate understanding of the health aspects of nonionizing radiation requires contributions from a variety of disciplines. I have reviewed the basic electrical concepts and terms used to describe the physical aspects of such radiation. The various portions of the spectrum, including microwaves, are defined and special interest is given to the "microwave region" because of its penetrating quality in man and animals. The various devices and systems involved in various microwave/RF systems are reviewed with emphasis on physical aspects and unique power and frequency characteristics. The basic radiation pattern in such systems is reviewed with an attempt to provide some gauge of likely exposure levels for a given power, frequency, and antenna type. The meaning of emission and exposure levels are distinguished as well as the relevance of the susceptibility of medical electronics to potentially hazardous interference. A foundation is laid to understand more detailed data on dosimetry and survey data and how animal experiments relate to man.

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DOSIMETRY—THE ABSORPTION PROPERTIES OF MAN AND EXPERIMENTAL ANIMALS*

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THE expanding usage of electromagnetic radiation has necessitated an understanding of its interaction with humans. Such knowledge is vital to evaluate and establish radiation safety standards, to determine definitive hazard levels, and to understand several of the interaction effects reported in the literature.[1] The need for research in this area is clearly exemplified by the widely disparate safety levels that are used worldwide at the present time. In the United States the safety level is 10 mW/cm.^{2} for long-term human exposure at any frequency and regardless of physical environment, whereas the recommended maximum safe power density in Eastern Europe and the U.S.S.R. is 1,000 times less at a level of 0.01 mW/cm.^{2} Several countries, including Canada[2] and Sweden,[3] are in the process of revising their safety standards downward from previously accepted levels of 10 mW/cm.^{2}

Biological studies of the effects of electromagnetic radiation have used laboratory animals such as rats, rabbits, etc. for the study of behavioral and biochemical changes. For these experiments to have any projected meanings for humans, it is necessary to be able to quantify the whole-body power absorption and its distribution for the various irradiation conditions. It is further necessary that dosimetric information be known for humans subjected to irradiation at different frequencies and under realistic exposure conditions.

Unlike ionizing radiation, where the absorption cross-section of a biological target is directly related to its geometric cross section, whole-body electromagnetic energy absorption has been shown[4-12] to depend strongly on polarization (orientation of electric field E of the incident

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waves), frequency, and such physical environments as a conducting ground and other reflecting surfaces. That a prescribed field strength of, say, 10 mW/cm.^{2} does not tell the whole story is best illustrated by examples from Schrot and Hawkins' work[13] on times to death of rats and mice at several frequencies and for different polarizations of incident waves. For a free-space irradiation power density of 150 mW/cm.^{2} at 985 MHz, mice oriented along the electric field (E-orientation) had convulsions after an average time of nine minutes, while similar animals oriented along the microwave magnetic field (H-orientation) lived through an experimental observation time of 60 minutes without significant stress. Identical power densities at several frequencies result in substantially different times to convulsion. For mice irradiated with an incident power density of 150 mW/cm.^{2} in the E-orientation, mean times to convulsion of 3,260 and 160 seconds were observed for 710 and 1,700 MHz., respectively.

We shall review the highlights of current knowledge of elecromagnetic absorption by man and animals. Most of the work to date has concentrated on the mathematically and experimentally simpler plane wave, far-field irradiation conditions, but recent research has also included such conditions as the presence of ground reflecting surfaces of high conductivity and groups of animals.

TECHNIQUES

Carefully proportioned, reduced scale models of man have been used to determine the mass-normalized rates of electromagnetic energy absorption (specific absorption rates or SARs) at different frequencies and for different conditions of irradiation.[9]

The highlights of the above results have been checked by experimentation with small laboratory animals[9,12] from 25 gram mice to 2,245 gram rabbits. The SARs are determined by measuring the colonic temperature elevation of anesthetized animals or by calorimetric determination of the absorbed dose by freshly killed animals.

Prolate spheroidal[5,8,14] and ellipsoidal[15] models have been used for theoretical calculations for man and animals at frequencies up to and slightly beyond the resonant region. For very high frequencies, a geometrical optics method has been developed to estimate power absorption in prolate spheroidal[16] and cylindrical models[17] of man. It is shown that the dependence of whole-body-averaged SAR on both frequency and polarization of the incident fields may be estimated using prolate spheroidal or ellipsoidal models, but the distribution of energy deposition through the body cannot be determined from such crude models.

Moment-method solutions for an improved model of man[10] have given good correlation with experimental data (see Figure 4). These calculations have also led to the identification of the frequency regions for peak absorption (resonance) in arms and the head.

The effects of layering on energy deposition have recently been studied for a multilayered[18] model of man. The layering information required for the multilayered model was obtained from published anatomic cross-sections.[19,20] Specific tissue thicknesses were used for 79 horizontal cross-sections of man and a layering resonance (interpreted as due to impedance matching provided by the thicknesses of the outer layers) calculated for each of the individual cross sections based on a planar model. These calculations demonstrate a broad layering resonance frequency of 1,800 MHz. for an adult human being.

State of the Knowledge for Electromagnetic Absorbed Dose in Man and Animals

Free-space irradiation condition. The condition studied most extensively[4-10,14-18] is that of free-space irradiation of single animals. Whole-body absorption of electromagnetic waves by biological bodies is strongly dependent[4,5] on the orientation of the electric field (E) relative to the longest dimension (L) of the body The highest rate[4,6,8] of energy deposition occurs for $E \| \hat{L}$ (E-orientation) for frequencies such that the major length is approximatly 0.36 to 0.4 times the free-space wave-length (λ) of radiation. Peaks of whole-body absorption for the other two configurations (major length oriented along the direction (k) of propagation, $k \| \hat{L}$ or k-orientation, or along the vector H of the magnetic field, $H \| \hat{L}$ or H-orientation) have also been reported[4,9] for $\lambda/2$ on the order of the weighted averaged circumference of the animals.

For each of the orientations of the major length along the E-, k-, and H-, respectively, two distinct exposure conditions are possible. These are:

For E-orientation ($E \| \hat{L}$):

1) Power propagating from front to back
2) Power propagating from arm to arm

For k-orientation (k | | $\hat{L}$, power propagating from head to toe:

3) E from front to back
4) E from arm to arm

For H-orientation (H | | $\hat{L}$:

5) E from front to back
6) E from arm to arm

A 5 to 15% larger whole-body absorption is found for cases 2 and 6 for E- and H-orientations, respectively. The greatest difference in absorption[7] is found for k-orientation where a 50% increase in the overall absorption is measured for electric field from arm to arm as compared to the case where the electric field is from front to back of the body. These observations have since been confirmed by below-resonance calculations[15] based on an ellipsoidal model of man.

Curves for whole-body absorption (fitted to the experimental data) for models of man exposed to radiation in free space are given[9] in Figure 1. For each of the indicated orientations, the above configurations resulting in an optimum power deposition were used.

For the most absorbing E-orientation, the whole-body absorption curve A may be discussed in terms of five frequency regions:

Region I—Frequencies well below resonance ($L_\lambda < 0.1$-0.2). An f^2 type dependence derived theoretically and checked experimentally by Durney and coworkers.[21]

Region II—Subresonant region ($0.2 < L/_\lambda < 0.36$). An $f^{2.75}$ to f^3 dependence of total power deposition has been experimentally observed for this region.

Region III—Resonant region ($L/_\lambda \sim 0.36$-0.4). A relative absorption cross section,[7] defined by electromagnetic absorption cross section/ physical cross section, S_{res} on the order of 0.665 L/2b (derivable also from antenna theory) has been measured in this region, where L is the major length of the body and $2\pi b$ is its weighted averaged circumference. For an adult human being, S_{res} of 4.2 corresponds to SAR. $L_m/1.75 \sim 2.16$ W/kg. for an incident power density of 10 mW/cm.^{2} For a man of 1.75 m. height, the resonance frequency is on the order of 62-68 MHz.

Region IV—Supraresonant region to frequencies on the order of 1.6 S_{res} times the resonance frequency f_r (for human beings, this covers the region $f_r < f < 7\ f_r$). A whole-body absorption reducing as $(f/f_r)^{-1}$ from the resonance value has been observed.

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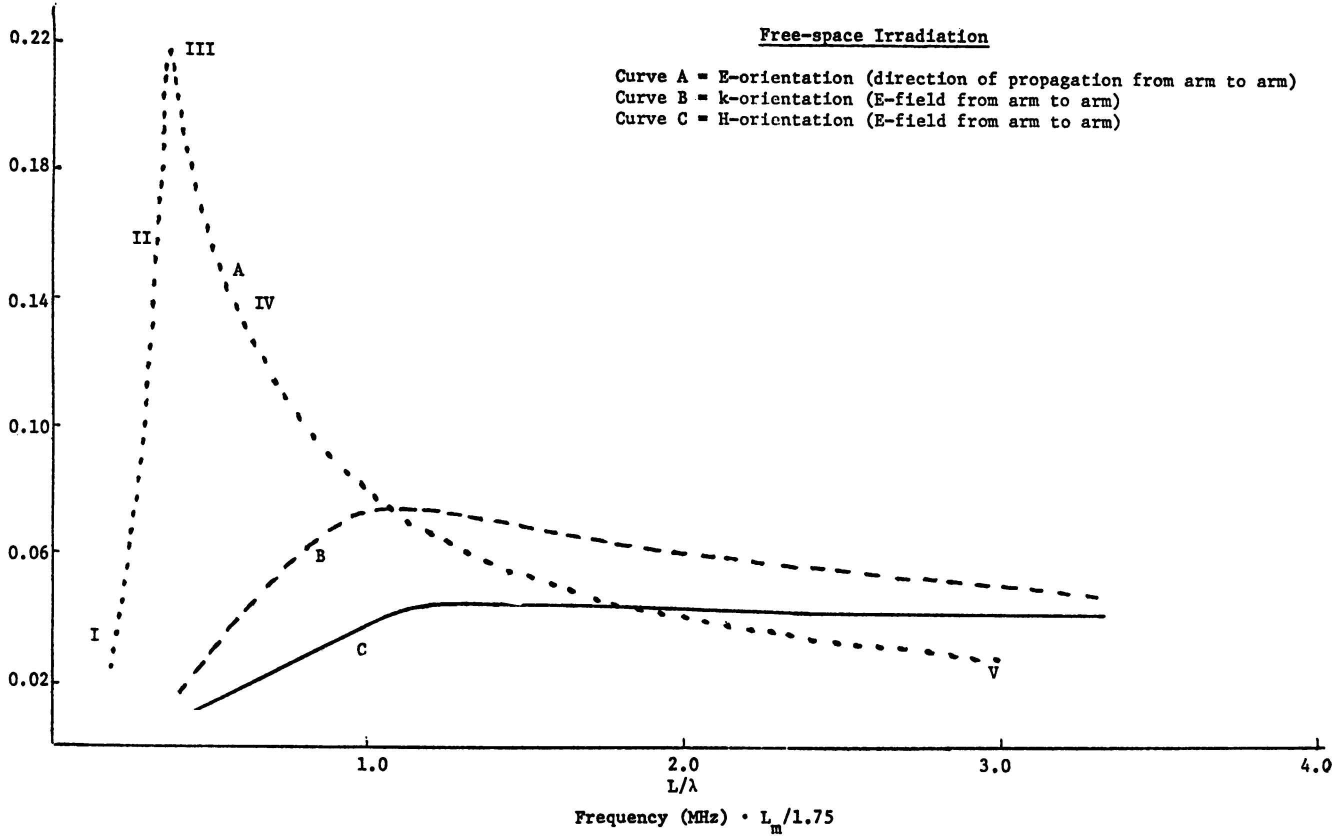

Fig. 1. Whole-body-averaged SAR for models of human beings for incident fields of 1 mW/cm.²

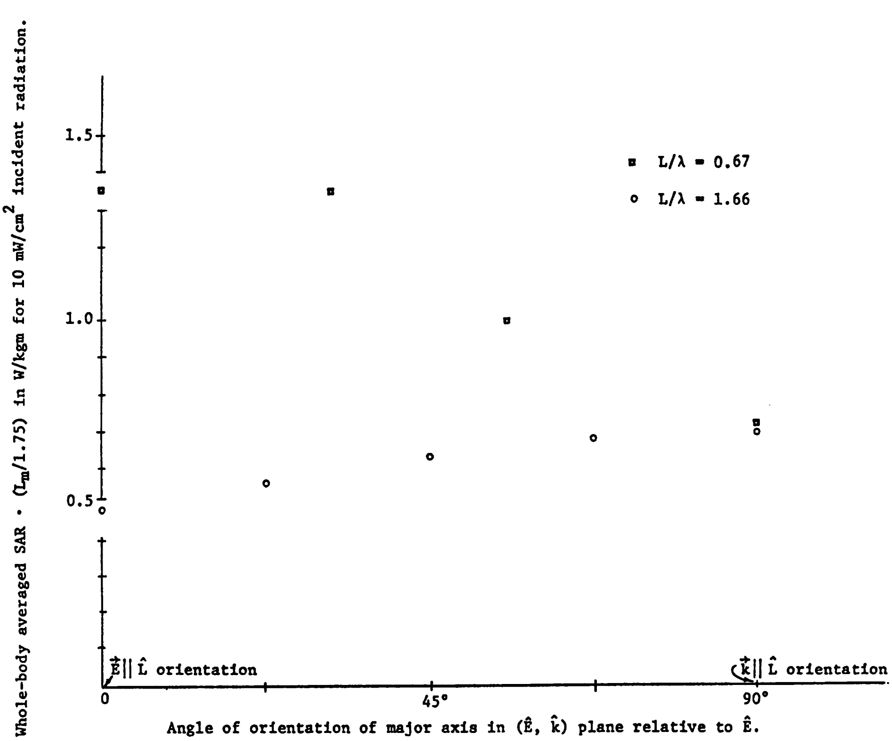

Fig. 2. Whole-body-averaged SAR for a saline-filled model of man for irradiation in the free field. The data points are for angles intermediate to $E||\hat{L}$ and $k||\hat{L}$ orientations.

Region V—f >> f_r region. The S parameter should asymptotically approach the "optical" value, which is (1—power reflection coefficient) or about 0.5.

In comparing the absorptions for various orientations (Figure 1), the following points are noteworthy:

1) For frequencies $(4\text{-}5)f_r < f < (8\text{-}9)f_r$, there is little distinction between the total power absorbed for the various polarizations. For human beings, this corresponds to (frequency in MHz.) × (height in meters/ 1.75), to a range of frequencies between 250 and 570 MHz.

2) The resonances for k- and H-orientations are not very sharp. In fact, for H-orientation, the value gradually reaches a peak value and stays at that value for higher frequencies.

Intermediate angles of body orientation. Body orientations intermediate to E and H vectors have previously[14] been considered analytically. It has

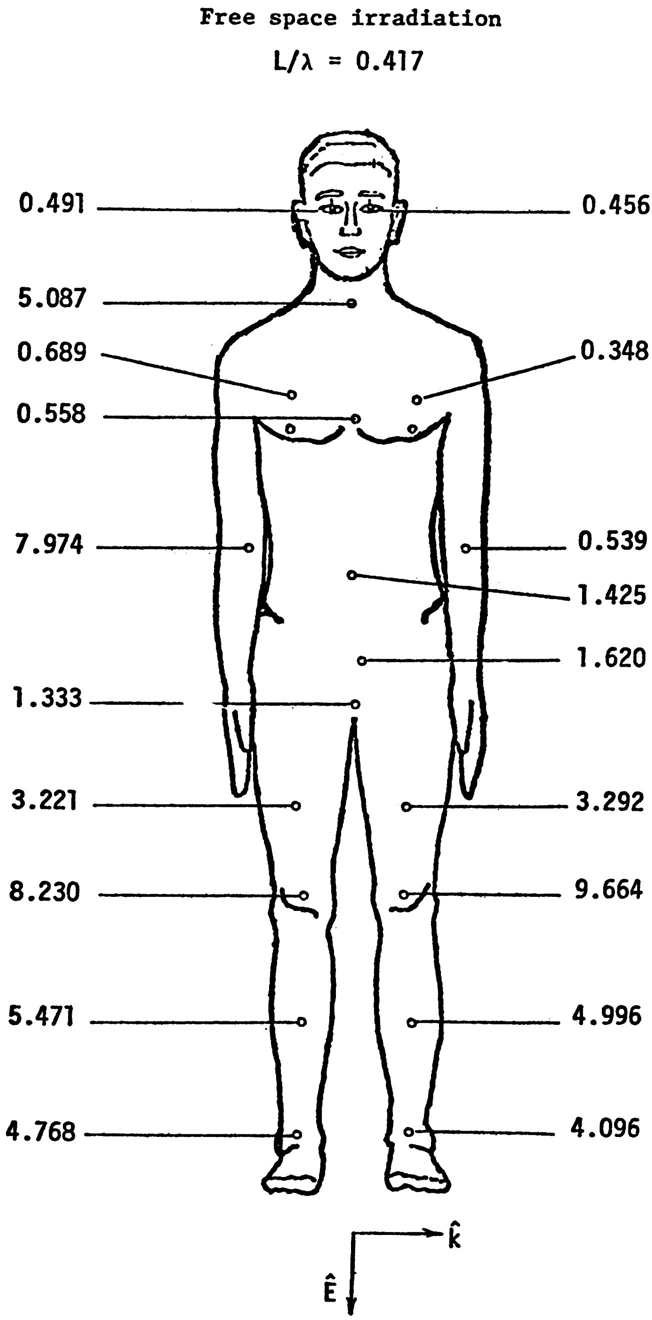

Fig. 3. Distribution of power deposition for a human under free-space irradiation. The numbers indicated are relative to whole-body-averaged SAR of $(1.75/L_m) \cdot 1.88$ W/kg. for 10 mW/cm.^{2} incident fields.

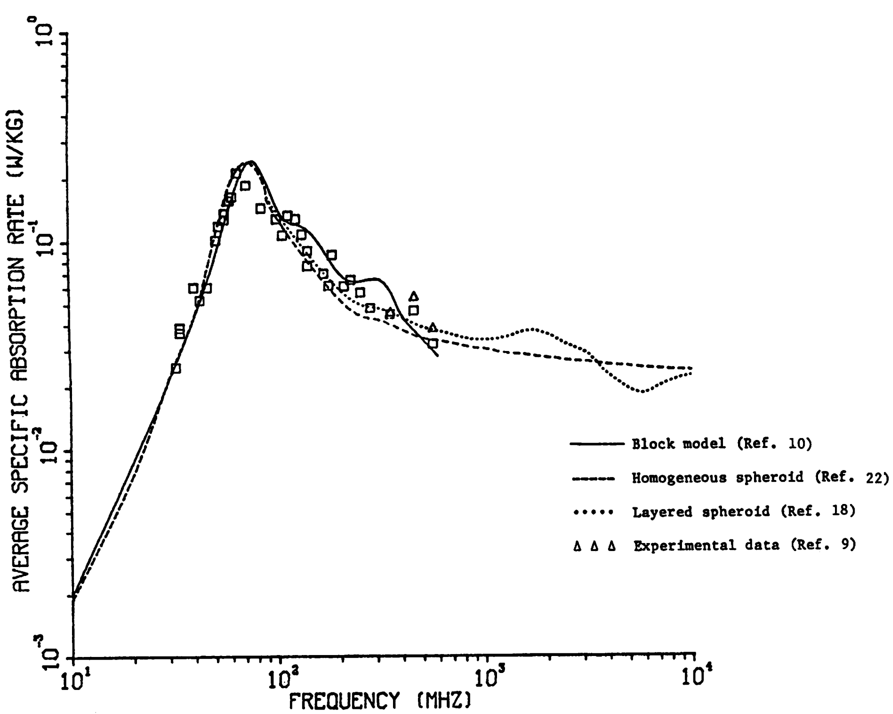

Fig. 4. Whole-body-averaged SAR for a model of man exposed to a broadside incident plane wave for E-orientation. (Incident power density = 1 mW/cm.²)

been shown that the SAR for major axis $\hat{L}$ making an angle θ relative to E in the ($\hat{E}$, $\hat{H}$) plane is given by $[(SAR)_{E||L} \cos^2 + (SAR)_{H||L} \sin^2 \theta]$. Experiments were performed to measure the SARs for different body orientations in the ($\hat{E}$, $\hat{k}$) plane. This case has to date been difficult to handle analytically. Measurements were performed at 2,450 MHz. ($L/_\lambda$ = 1.66) with a 20.3 cm. saline-filled doll at different angles of orientation relative to E. The whole-body SARs calculated for full-scale man are plotted in Figure 2. The SAR varies smoothly from E-orientation to k-orientation values as the body orientation is altered between the two extreme positions in this plane. Measurements at 987 MHz. ($L/_\lambda$ = 0.67) demonstrate a similar situation and these values are also plotted in Figure 2. Unlike the situation for $L/_\lambda$ = 1.66, however, the E-orientation SAR for $L/_\lambda$ = 0.67 is higher than that for k-orientation (see Figure 1).

Distribution of power deposition under resonance conditions. The mea-

TABLE I. EMPIRICAL EQUATIONS FOR WHOLE-BODY-AVERAGED SAR FOR MAN MODELS FOR CONDITIONS OF FREE-SPACE IRRADIATION

$E \,||\, \hat{L}$ polarization

$$\text{Resonant frequency } f_r = 11{,}400/L_{cm.} \text{ MHz.} \tag{1}$$

For *subresonant* region—$0.5\, f_r < f < f_r$:

$$\text{SAR in mW/g. for 1 mW/cm.}^2 \text{ incident plane wave field} = \frac{0.52\, L^2_{cm.}}{\text{mass in g.}} \left(\frac{f}{f_r}\right)^{2.75} \tag{2}$$

For *supraresonant* region—$f_r < f < 1.6\, S_{res}\, f_r$:

$$\text{SAR in mW/g. for 1 mW/cm.}^2 \text{ incident plane wave field} = \frac{5{,}950}{f_{MHz.}} \; \frac{L_{cm.}}{\text{mass in g.}} \tag{3}$$

where $L^2_{cm.}$ is the long dimension of the body in centimeters, and

$$S_{res} = 0.48 \left(\frac{L^3_{cm.}}{\text{mass in g.}}\right)^{1/2} \tag{4}$$

sured pattern of energy deposition for conditions of highest absorption is shown in Figure 3. For free-space irradiation, SARs considerably higher than the whole-body average are observed for the neck, legs, and front elbow region, with the lower torso receiving SARs comparable to the average value and the upper torso receiving SARs lower than the average value. The deposition rates at the hot spots may be 5 to 10 times the whole-body-averaged SAR.

Comparison with theoretical calculations. Comparison in Figure 4 of the various models of man shows a fairly good correlation of the experimental and theoretical values, giving thereby a basis for confidence in the whole-body absorbed dose for the highest absorbing E-orientation. A major contribution of the numerical calculations with the block model of man (curve A) is to reveal a fine structure to whole-body absorption in the supraresonance region. Minor peaks in this region at 150 MHz. and at 350 MHz. are ascribed to maxima of energy deposition in such various body parts[10] as the arm and the head.

The calculations for a multilayered model[18] of man show that layering may only be neglected at frequencies below 500 MHz. where a homoge-

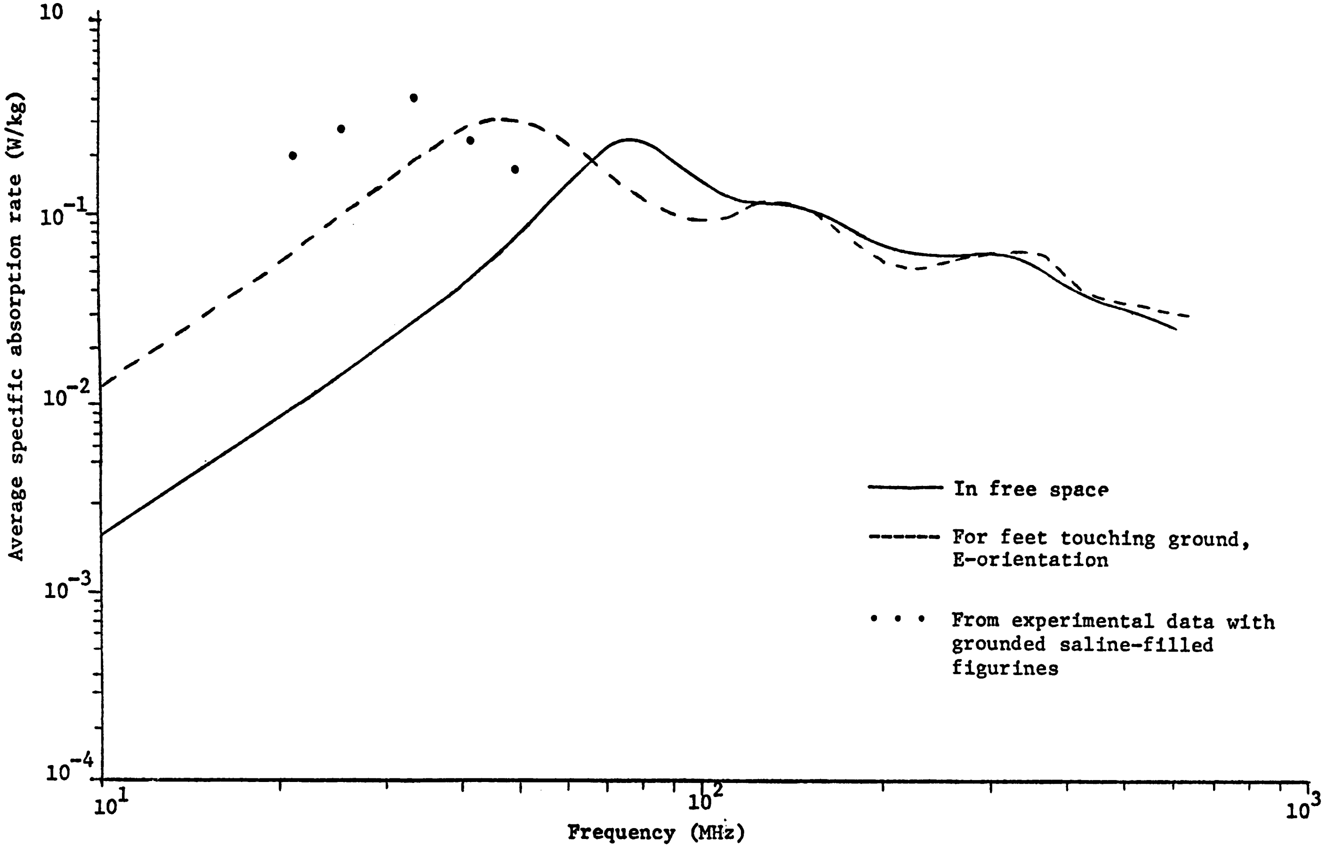

Fig. 5. Whole-body SAR for homogeneous model of man. Incident power density of 1 mW/cm.^{2}, E-orientation; k ventral to dorsal for numerical calculations and from arm to arm for experiments with saline-filled figurines.

neous model is appropriate, or above 10 GHz. where absorption is generally restricted to the skin. Also shown in curve C is a broad layering-caused peak in whole-body absorption at a frequency of 1,800 MHz., where a deposition 34% larger than that for the homogeneous model (curve B) is obtained.

The empirical equations for SAR for E-orientation. The supraresonant frequency dependence and the observed 1/f dependence in the supraresonant region have been used to develop the empirical equations[9] in Table I for whole-body-averaged SAR for man models for E-orientation. Because human subjects cannot be used for experimentation, the empirical equations of Table I have been checked by experiments with six animal species[12] and found fairly accurate. For reasons not yet understood, measured SAR values for experimental animals are approximately 59% higher than those given by equations 2 and 3, derived from experiments with model figurines.

Electromagnetic Absorption for Man and Animals in the Presence of Nearby Ground and Reflecting Surfaces

Ground effects. Only highly conducting (metallic sheet) ground of infinite extent has been considered to date. All measurements and calculations of grounding effects have assumed that a man is standing on or above such a ground. Figure 5 shows the calculated[11] values of SAR for the block model of man with feet in conductive contact with ground and compares this to values calculated for free-space irradiation. Also shown in the same figure are values measured[7,9] with saline-filled figurines exposed to irradiation in the E-orientation at different frequencies in the monopole-above-ground[6] radiation chamber. This chamber, which uses a radiator that is a quarter-wave monopole above ground, provides in conjunction with figurines a proper simulation of grounding effects on energy absorption. Even though the peak SARs of calculated data and measured values agree, the resonant frequencies for the two models differ. The calculated resonant frequency of man in conductive contact with ground is 47 MHz. as compared to 77 MHz. for man in free space. The corresponding frequencies obtained from saline-filled figurines are 34.5 and 68 MHz., respectively. The reason for this discrepancy is not clear.

Using biological phantom-filled figurines, the pattern of energy deposition is measured for grounded resonance condition and is shown in Figure

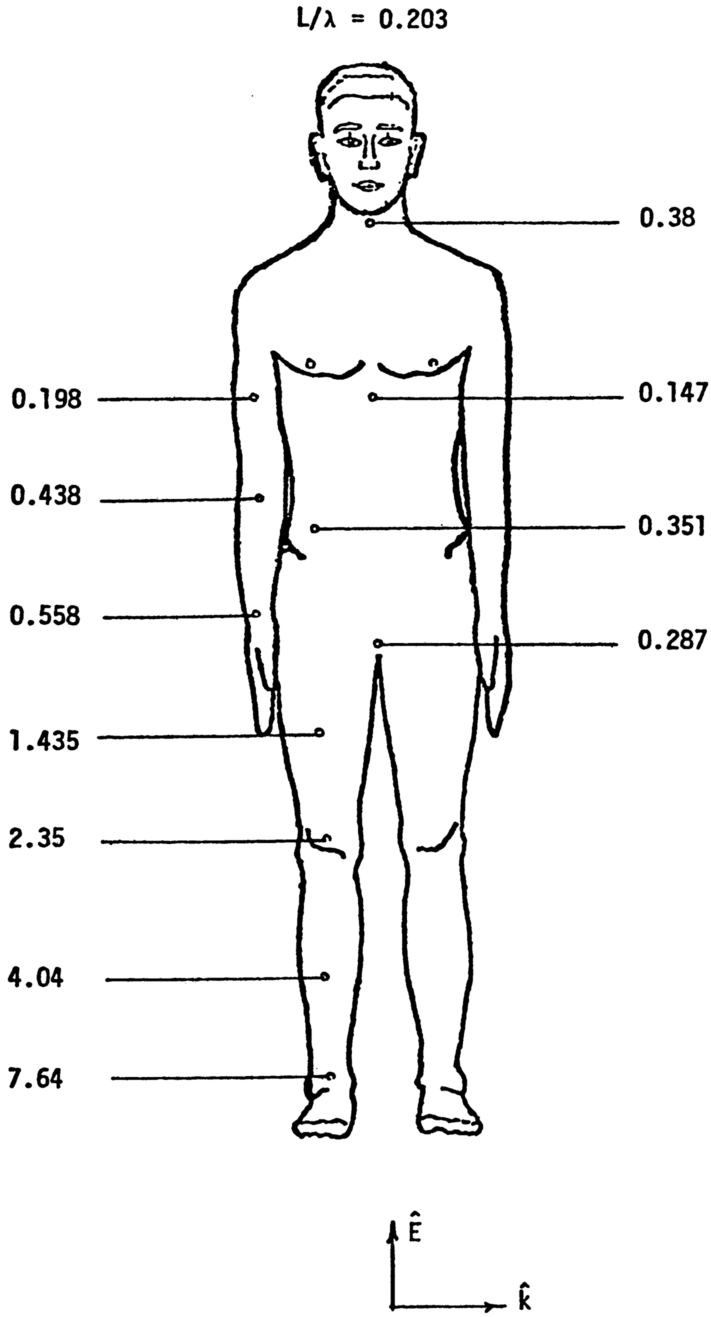

Fig. 6. Distribution of power deposition for a human being with feet in electrical contact with the ground. The numbers are relative to whole-body-averaged SAR values of $(1.75/L_m) \cdot 4.0$ W/kg. for 10 mW/cm.[2]

6. The highest SARs in this case are observed for the ankles and the legs. As in the case of free-space irradiation, the deposition rates at the hot spots are, once again, a factor of 5 to 10 times larger than the whole-body-averaged SAR under these conditions.

The nature of the ground effects on SAR (for E-orientation) is such that even a small separation[11,23] from ground (to break conductive contact) is sufficient to eliminate much of the ground effect. For separations from ground of more than three to four inches, the total energy deposition and its distribution are identical to those for free-space irradiation conditions. Even for a man model in conductive contact with a perfect ground, the energy deposition in the supraresonance region ($f > 2\text{-}3\ f_r$) is comparable[11] to that for conditions of free-space irradiation.

Reflector effects. Here, too, only highly conducting reflecting surfaces[9,11] have been considered thus far and most of the work has concentrated on frequencies close to the resonance region and for E-orientation. Highly enhanced SARs by factors as large as five and 27, respectively, have been measured using saline-filled figurines in the presence of flat and 90° corner-type reflectors of aluminum of plate dimensions no bigger than a few wavelengths. For resonant targets, the measured enhancements (over free-space values) of electromagnetic absorption in human models conform to the gains[24,25] of a half-wave dipole antenna in the presence of such reflectors. Indeed, for incident plane waves for E-orientation, most of the observed results are as though the irradiated target acted as a pick-up half-wave dipole in the presence of reflecting surfaces. The times-to-convulsion of ~100 gram rats at incident power densities of 3 to 20 mW/cm.^{2} confirm the highlights of these results. Some of the results are illustrated in Figure 7.

Head resonance. As mentioned above, we have identified a frequency region for the highest rate of energy deposition in the head. The head resonance[12,26] occurs at frequencies such that the head diameter is approximately one quarter of the free-space wavelength. For the intact adult human head, the resonance frequency is estimated to be of the order of 350-400 MHz. At head resonance the absorption cross section is approximately three times the physical cross section with a volume-averaged SAR about 3.3 times the whole-body-averaged SAR. Both values greatly exceed numbers reported earlier for spherical models of the isolated human head.[27,28] For reasons not as yet understood, the head resonance is observed for E- and k-orientations but not for H-orientation.

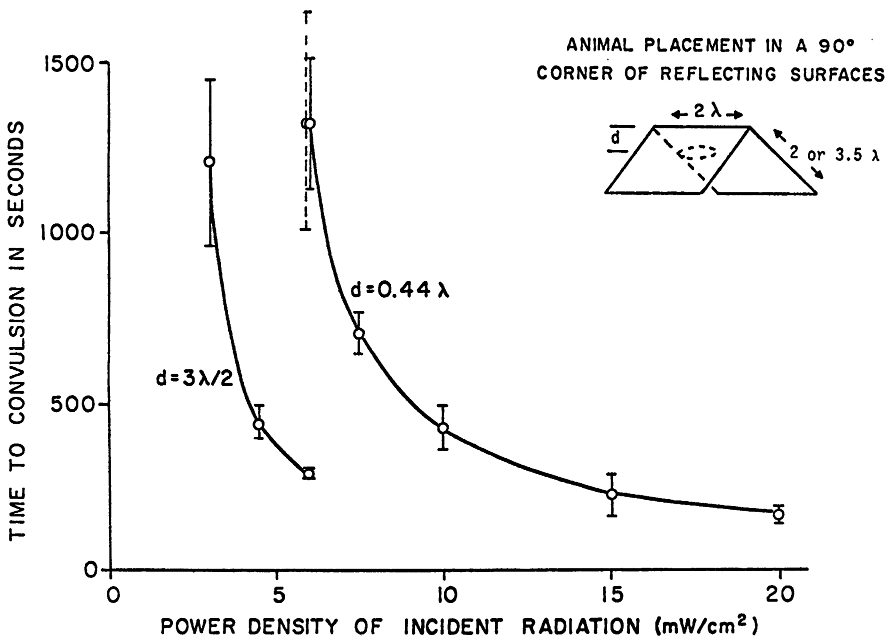

Fig. 7. Times to convulsion (±SD) of 100 g. rats at the resonance frequency of 987 MHz. for two distances of the animal from the corner of the reflector. (The dashed line and the data for d = 3 λ/2 were obtained with a corner reflector of dimensions 3.5 λ × 2.0 λ.) Reproduced by permission from Gandhi, O.P. et al.: Deposition of electro-magnetic energy in animals and in models of man with and without grounding and reflector effects. *Radio Sci. 12:*39-47, 1977 (copyrighted by American Geophysical Union).

Numerical calculations[26] using 144 cubical cells of various sizes to fit the shape of the human head (340 cells for the whole body) give local SARs at "hot spots" (above the palate and the upper part of the nape of the neck) that are about five times the average values for the head. Enhanced absorption in the head region at head-resonant frequencies may be important in studies of the behavioral effects, blood-brain barrier permeability, cataractogenesis, etc., and needs to be examined at length.

Multianimal effects. It has been shown that for resonant biological bodies close to one another, antenna theory may be used to predict the modification in SAR relative to free-space values. For two resonant targets separated by 0.65 to 0.7 λ, the highest SAR, 150% of free-space value, can result for man and animals for E-orientation for frontally (broadside) incident plane waves. For three animals in a row with an interanimal spacing of 0.65 λ, the central animal SAR would be roughly two times, while the two end animals will receive an SAR that is approximately 1.5 times that for an isolated animal.

Full implications of the multibody effects on SAR are not completely understood, even though block model calculations and pilot experimental data[12] with anesthetized rats at 2,450 MHz. demonstrate that similar enhancements may also occur for subresonance and supraresonance regions.

Relative Doses of Electromagnetic Absorption at Different Frequencies

To demonstrate the great disparity of electromagnetic absorption at different frequencies for a given animal size, equivalent power levels for a given time-to-convulsion were measured for 100 g. rats placed 3 $\lambda/2$ in front of a 90° corner reflector at 987 and 2,450 MHz. Another objective of these experiments was to see if whole-body integrated dose rather than its distribution was the important parameter in determining the time to convulsion.

Substantially different distributions[7] have previously been reported for the two frequencies with models of man, and a similar situation is expected for 100 g. rats. Because of the 1/f reduction in the absorbed energy for the supraresonant region, a free-space whole-body deposition rate of 2.45/0.987 or 2.48 times is expected at 987 MHz. compared to that at 2,450 MHz. Further, a reflector-caused enhancement in the SAR is considerably larger for near-resonance size targets than supraresonant conditions. A ratio of 27.5/9.3 or 2.96 is expected[3] on this account for the reflector-caused enhancements in the SARs between 987 and 2,450 MHz. ($L/\lambda \sim 0.42$ and 1.04 at the respective frequencies). A total SAR of $1/(2.48 \times 2.96) = 1/7.34$ times the value at 987 MHz. is therefore projected for irradiation of 100 g. animals at 2,450 MHz.

If the hypothesis, that whole-body integrated dose is the all-important parameter, is true, comparable times to convulsion should be observed for 5 mW/cm.^{2} at 987 MHz. (Figure 7) and for 36.7 mW/cm.^{2} incident fields at 2,450 MHz. The selection of 5 mW/cm.^{2} for $d = 3\ \lambda/2$, 987 MHz. avoids the asymptotic regions and is on the knee of the time-to-convulsion curve (Figure 7).

The average times to convulsion for 100 g.* rats at 2,450 MHz. for

*Somewhat lighter animals with weights of 81.1 ± 5.6 were used for these experiments. For the experiments of Figure 7, for $d = 3\ \lambda/2$, the animal weights[9] were 104 ± 8.3 g.

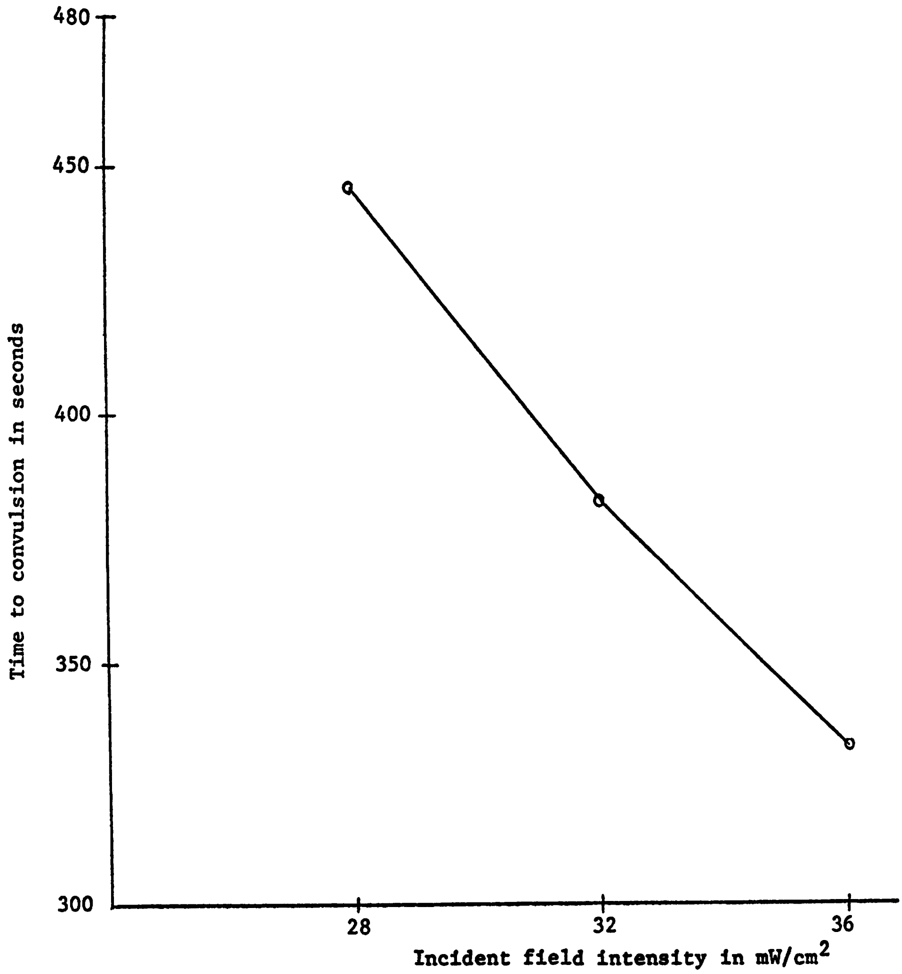

Fig. 8. Mean times to convulsion of 100 g. rats at 2,450 MHz. for a distance d = 3 λ/2 from a 90° corner of reflecting plates.

three incident power levels are plotted in Figure 8. Time-to-convulsion of 365 seconds comparable to 5 mW/cm.^{2} incident fields at 987 MHz. is observed for 33.2 rather than 36.7 mW/cm.^{2} projected from measurements with saline-filled man models of comparable L/λ. Thus, there is a departure of only about 10% between the projected and observed values. Indeed, the difference may have been even smaller if heavier animals comparable in weight to those for Figure 7 had been used because higher SARs result

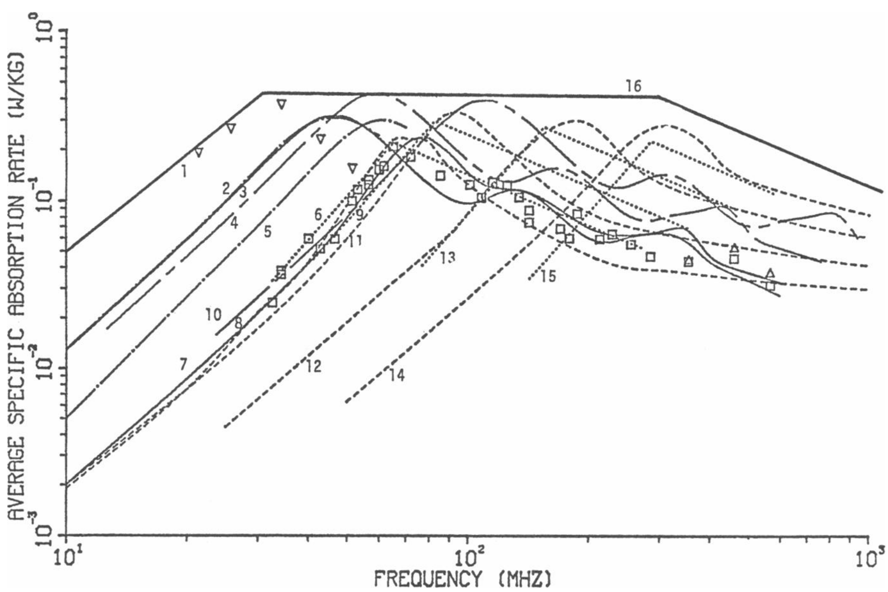

Fig. 9. Whole-body-averaged SAR for an adult human, 10-year-old child, one-year-old child, and a human infant. Power density = 1 mW/cm.[2] The results of various researchers are used for cross comparison. The outer envelope gives the maximum SAR for any of the human sizes at a given frequency. Legend for curves (left to right): 1. Experimental results scaled from saline-filled figurines under grounded conditions—adult human (from Figure 5). 2. (solid curve) Numerical calculations with a block model of man—conductive contact with ground (from Figure 5). 3. (chain-dot) Empirical—adult human in conductive contact with ground (Ref. 22). 4. (chain-dash) Scaling of curve 2 for 10-year-old child (grounded contact). 5. (chain-dot) Empirical—adult human 3 cm from ground plane (Ref. 22). 6. (dot) Empirical equation (from Table I)—adult human in free space. 7. (solid) Numerical calculations for a block model of man in free space with figurine experimental data shown by open squares and phantom experimental data shown by open triangles (Refs. 9, 10). 8. (dash) Prolate spheroidal model of man in free space (Ref. 22). 9. (dot) Empirical equation (from Table I)—10-year-old child. 10 (chain-dash) Scaling of curve 2 for one-year-old child (grounded contact). 11. (dash) Prolate spheroidal model of 10-year-old child (Ref. 22). 12. (dash) Prolate spheroidal model of a one-year-old child (Ref. 22). 13. (dot) Empirical equation (from Table I)—one-year-old child. 14. (dash) Prolate spheroidal model of a human infant (Ref. 22). 15. (dot) Empirical equation (from Table I)—human infant.

for smaller animals, and this may have contributed to somewhat lower values of field intensities needed at 2,450 MHz. for comparable times to convulsion.

These experiments demonstrate that because of a rapid hemodynamic dispersion of heat, the whole-body integrated dose and dose rates are important indices in the study of living animals.

TABLE II. METABOLIC RATES IN W/kg. FOR NORMAL HEALTHY HUMANS OF VARIOUS AGES

	Adult human being (20-24 year old male)	*Ten-year-old child*	*One-year-old child*	*Human infant*
		Whole-body-average values		
Sleeping	1.1			
Resting quietly (~ basal condition)	1.3	2.0	2.75	2.75
Sitting upright	1.5			
Standing (clerical work)	1.8			
Walking, 3 m.p.h.	4.3			
Bicycling	7.7			
Swimming	11.0			
		Local values		
Brain	11.0			
Heart muscle	33.0			

ELECTROMAGNETIC ABSORPTION FOR HUMANS: CONSIDERATIONS FOR AN ELECTROMAGNETIC SAFETY GUIDE

Figure 9 plots 15 individual curves for the specific absorption rates for a 70 kg., 1.75 m. tall average sized man; a 1.38 m. tall, 32.2 kg. 10-year-old child; a 0.74 m. tall, 10 kg. one-year-old child; and a 0.4 m. long, 3.5 kg. average sized human infant under various conditions. The theoretical and experimental results of various researchers are used in plotting these graphs. An incident power intensity of 1 mW/cm.^{2} is assumed for the highest absorption E-orientation. Ground contact conditions are assumed for an adult human, a 10-year-old child, and a one-year-old child, but not for a human infant.

Figure 9 also shows an overall "umbrella" type curve 16, which gives the maximum SAR for any of the human sizes under the various conditions. Peaks of absorption for the various human sizes fall in the frequency band 30 to 300 MHz. There is in general an f^2 type rise in SAR on the low frequency side and a 1/f type fall in SAR for the supraresonant region. For 1 mW/cm.^{2} measured* environmental fields over a whole-body exposure situation, it is clear from Figure 9 that the maximum whole-body-averaged SAR over the peak absorption region of 30 to 300 MHz. is always less than or equal to 0.42 W/kg. Maximum SAR at hot spots may

*It is assumed here, of course, that any reflection-caused enhancements of power densities are already accounted for in actually-measured fields of 1 mW/cm.^{2}

be as much as an order of magnitude higher, but, as outlined earlier, these SARs do not necessarily translate into higher temperatures because of a rapid hemodynamic dispersion of heat.

These SARs may be compared to the typical metabolic rates[29] for human species that are listed in Table II.

The implications of the various levels of SAR are not clear because the study of microwave biological effects is still in its infancy. For short-term exposures, replicable biobehavioral effects (mostly activity decrements) have generally been observed in small laboratory animals for SARs on the order of 2 to 6 W/kg. The literature also is full of effects at higher rates of energy deposition which may be ascribed to additional thermal loads imposed on the body. Long-term biobehavioral experiments are by and large lacking in the United States and Western European literature, and one cannot therefore say with any certainty whether lower values of SARs will produce long-term biological effects.

Conclusions

The state of knowledge of electromagnetic absorption for man and animals has been presented in this paper. Densitometry is not of primary importance and for a given power density the absorbed dose can vary by orders of magnitude depending upon the frequency, animal size and its orientation, physical environments, etc.

Even though a great deal of progress has been made in the field of radiofrequency dosimetry, information is sorely lacking for realistic conditions of exposure such as the effects of finite size, finite conductivity, ground, and reflectors, and for the important problem of near-field and partial body exposures encountered by operators of electromagnetic radiation equipment for communications, radar, and for industrial and biomedical applications.

Questions and Answers

DR. LEONARD SOLON (Bureau for Radiation Control, New York City): You indicated that the maximum resonant absorption was at 68 megahertz, with a maximum absorption of 2.2 W/kg., yet some of your subsequent slides and descriptions departed from that. What was the reason for that discrepancy?

DR. GANDHI: 2.2 W/kg. for 10 mW/cm.^{2} incident fields corresponds to

0.22 W/kg. for 1 mW/cm.^{2} for an adult human. Subsequent slides were shown for incident power densities of 10 and 1 mW/cm.^{2} The deposition rates up to 0.42 W/kg. are possible at 1 mW/cm.^{2} because of the ground contact for a ten-year-old child. For the respective resonant frequencies, which scale inversely as the height of the individual, the SAR values scale roughly as (weight)$^{-1/3}$ and are therefore somewhat higher for a ten-year-old child as compared to a human adult.

DR. SOLON: What was the maximum SAR for a specific locus for 10 mW/cm.^{2} in terms of the very broad spectrum of parameters that you addressed?

DR. GANDHI: The highest possible whole-body-averaged SAR for any of the human sizes for 10 mW/cm.^{2} could be as high as 4.2 W/kg. and about 5 to 10 times higher at the hot spots. Our results so far show that the high SAR values at the hot spots do not necessarily translate to higher temperatures. These are the spots for high rates of energy deposition and not necessarily high temperature spots because of the hemodynamic equalization. We feel, on the basis of experiments with rats, that the hemodynamic equalization actually ends up conducting the heat away from the so-called hot spots. We have looked at times to convulsion at various frequencies where we have matched the whole-body-averaged values but not the hot spot values. We obtained similar times to convulsion, as though the hot spots were being homogenized.

DR. BASIL WORGUL (Columbia University College of Physicians and Surgeons): Given a fixed dimension, what is the lower limit of the scaling? What allowance do you have for the lower limits of scaling in terms of absorption? That is, how small an animal can you use and how far can you extrapolate animal data?

DR. GANDHI: We checked the highlights of our results using small laboratory animals from 25g. mice to 2,250g. rabbits. We think that we could go down on size to still smaller animals. One thing that happens as we go down from the resonance condition is the rapid decrease of the energy deposition. Consequently, there is so little absorption for the kind of fields that we can conveniently set up in the laboratory that there is very little heating of the animals.

DR. WORGUL: Do you feel confident that you could predict the absorption from a larger model going to a smaller model?

DR. GANDHI: We do.

DR. JOHN OSEPCHUK: How far above resonance does one have to go before energy is absorbed from the surface and then, on the lower side, how far below resonance before one starts to get quasistatic, in other words, very greatly reduced uniformity?

DR. GANDHI: For a human being, the energy deposited, to a large extent, is in the surface layers above, about 10 gigahertz. That is where one has little or none of the effects in energy deposition because of multiple layers of tissue of which a body is composed. For frequencies less than approximately 10 megahertz for a human being, the rate of energy deposition is quite accurately given by the quasistatic analysis.

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RADIATION SURVEYS—MEASUREMENT OF LEAKAGE EMISSIONS AND POTENTIAL EXPOSURE FIELDS

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THE entire population is intermittently and continuously exposed to radio waves from a variety of sources: radio and television broadcast systems, radar, citizen band radios, microwave communications systems, medical diathermy units, industrial sources, and microwave ovens. The term "radio waves" applies to electromagnetic radiation frequencies between 3 kilohertz and 300 gigahertz and, hence, includes the microwave frequency band, 300 megahertz to 300 gigahertz. In preceding papers, Osepchuck[1] reviewed the sources and basic characteristics of radio waves and Gandhi[2] discussed dosimetry and the absorption of radio waves in both humans and experimental animals. We shall present the results of measurements of radiofrequency electromagnetic fields from a number of different sources. To do this it is convenient to define two kinds of exposure environments. One occurs at distances far from individual sources and is due to the superposition of fields from many sources operating at different frequencies, and we call this the "general radiofrequency environment." In a relative sense, whether exposure in the general environment is high or low depends on the locations and types of sources that contribute to the exposure. The other kind of exposure, actually a special case of the first, occurs so close to a particular source or sources that the radiofrequency environment is dominated by the fields of that source and we call this the "specific source radiofrequency environment."

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Quantities and Units

The commonly used quantity for the rate of exposure to radio waves is the areal power density denoted by the symbol S. The internationally accepted unit is the watt per square meter ($W/m.^2$), but for historical reasons exposure rate is often expressed in milliwatts (mW) or microwatts (μW) per square centimeter ($cm.^2$), e.g., 1 $W/m.^2$ = 0.1 $mW/cm.^2$ = 100 $\mu W/cm.^2$ Radio waves are electromagnetic waves and have both electric and magnetic components. The electric component, E, is the electric field strength and its units are volts per meter (V/m.). The magnetic component, H, is the magnetic field strength and its units are amperes per meter (A/m.). For a point source or for distances far enough from an extended source that it can be treated as a point source, the power density is proportional to the squared value of either the electric or magnetic field strength, i.e.,

$$S(W/m.^2) = E^2(V/m.)^2/377 \text{ (ohms)} \qquad [1]$$

$$= 377 \text{ (ohms) } H^2 \text{ } (A/m.)^2 \qquad [2]$$

where we have taken 377 ohms as the impedance of free space.

Most exposures in the general radiofrequency environment can be treated as the superposition of fields from point sources, i.e., exposures to plane wave electromagnetic fields or equivalently exposures in the so-called "far-field" of antennas. Conversely, most exposures of interest in specific environments occur in the so-called reactive "near-field" of the source and equations [1] and [2] generally do not apply. For near field exposures it is often better to specify the magnitudes of the electric and magnetic fields rather than an arbitrarily derived "equivalent" power density. We shall return to this point in our discussion of specific source environments. For a discussion of the complex electromagnetic fields that occur in the near-field the reader may consult standard texts.[3]

Concluding our discussion of quantities and units, we recall that for electromagnetic waves the product of the frequency, ν, and the wave length, λ, is approximately equal to the speed of light in air, i.e.,

$$\lambda(m) \times \nu \text{ (Hz.)} = 3 \times 10^8 (m/s) \qquad [3]$$

TABLE I. ANTENNAS USED FOR ENVIRONMENTAL RADIOFREQUENCY MEASUREMENTS

Frequency (MHz.)	*Use*	*Antenna*
0-2	VLF communications and AM standard broadcast	Active vertical monopole
54-88	Low VHF television broadcast	Two horizontal orthogonal dipoles
88-108	FM broadcast	Three orthogonal dipoles
150-162	VHF land mobile	Vertical coaxial dipole
174-216	High VHF television broadcast	Two horizontal orthogonal dipoles
450-470	UHF land mobile	Vertical coaxial dipole
470-806	UHF television broadcast	Horizontal polarized directional log periodic

Frequency is specified in cycles per second or hertz (Hz.) and wave length in meters. The radiofrequency spectrum extends from 3,000 hertz (or 3 kilohertz) to 300 billion hertz (or 300 gigahertz) and this corresponds to a wavelength range of 100,000 meters to 1 millimeter. Microwaves fall into the portion of the radiofrequency spectrum above 300 million hertz (or 300 megahertz), i.e., microwaves are radio waves with wavelengths between 1 m. and 1 mm. Most sources of interest fall into a frequency range conveniently described in terms of megahertz (MHz.).

THE GENERAL RADIOFREQUENCY ENVIRONMENT

The general radiofrequency environment consists of fields from many sources operating on many different frequencies. Proper measurement usually requires a sophisticated measurement system. In urban areas, the general environment is dominated by radio and television broadcast transmission.[4-8] The frequency bands of the principal contributors are listed in Table I. To determine the need for guidelines to control environmental levels of radio waves, the Environmental Protection Agency began making measurements in these bands using a system especially designed for this purpose. Briefly, the measurement system which has been described in detail elsewhere[9] consists of the antennas listed in Table I, a scanning radio receiver called a spectrum analyzer that measures electric field strength as a function of frequency, and a small computer to process and to store data. To provide mobility, the entire system is housed in a van equipped with its own power source.

TABLE II. POPULATION EXPOSURE IN 15 U.S. CITIES (54-900 MHz.)

City	*Median exposure* ($\mu W/cm.^2$)	*Percent exposed* $<1\ \mu W\text{-}cm.^2$
Boston	0.018	98.50
Atlanta	0.016	99.20
Miami	0.0070	98.20
Philadelphia	0.0070	99.87
New York	0.0022	99.60
Chicago	0.0020	99.60
Washington	0.009	97.20
Las Vegas	0.012	99.10
San Diego	0.010	99.85
Portland	0.020	99.70
Houston	0.011	99.99
Los Angeles	0.0048	99.90
Denver	0.0074	99.85
Seattle	0.0071	99.81
San Francisco	0.002	97.66
All cities	0.0048	99.44

This measurement system has been used to make measurements at 486 sites in 15 cities with a combined population of more than 44 million. We have combined the results of these measurements, 1970 census data, and a propagation model to estimate population exposure-rate for each of the 15 cities. The results are summarized in Table II. Note that among the cities the median values differ by about an order of magnitude: from 0.002 $\mu W/cm.^2$ in Chicago and San Francisco to about 0.02 $\mu W/cm.^2$ in Boston and Portland. Also note that the percentage of the population exposed to less than 1 $\mu W/cm.^2$ is fairly uniform from one city to another, i.e., between 97 and 99%. The median value for all cities taken together is 0.005 $\mu W/cm.^2$ Table III gives the results of combining the estimates for all 15 cities. These data illustrate that the exposure rate is strongly skewed to lower values. Note that 50% of the population is exposed below 0.005, 90% below 0.05, and 98% below 0.5 $\mu W/cm.^2$

These population-exposure estimates do not include contributions from the AM broadcast band. The absorption of energy by humans at AM frequencies (0.535-1.605 MHz.) is orders of magnitude less than at FM and TV frequencies (54-890 MHz.).[10,11] If the contribution of AM frequencies were included, the power-density figures given in Table III would not increase by more than a factor of two. These exposure-rate estimates,

TABLE III. CUMULATIVE POPULATION EXPOSURE FOR 15 CITIES (54-900 MHz.)

Power density *($\mu W/cm.^2$)*	*Cumulative percent** *of population*
0.002	19.5
0.005	49.5
0.01	68.7
0.02	82.4
0.05	91.4
0.1	94.7
0.2	97.
0.5	98.8
1.0	99.4

*For example, 19.5% are exposed to levels less than 0.002 μW/cm.^{2}, 68.7% are exposed to levels less than 0.01 μW/cm.^{2}, etc.

based on census data, only apply to continuous exposure of people where they reside. They do not take into account population mobility, exposures at heights greater than 6 m. (20 ft.), the attenuation of signals by buildings, or periods of time when sources are not transmitting.

Both low- and high-power sources that operate at frequencies outside the broadcast bands do not contribute very much to the general radiofrequency environment,[4,5,12] though the contribution of the higher powered devices to specific source environments may be large. Low-power devices include: microwave relay links, personal radios such as radio telephones and citizens band, and the traffic radars used by law-enforcement agencies to measure the speed of vehicles. High power sources include: satellite communication systems, military acquisition and tracking radars, and civilian air-traffic control and air-route surveillance radars. All of these high powered systems use highly directive antennas, i.e., their beams have small cross-sectional areas and only a small volume of space is illuminated at any instant. For many of these systems the antenna is high above ground or is pointed two to three degrees above the horizon, thereby making exposure to the main beam improbable. Most radar systems rotate, further reducing the average exposure. The contribution of radars to the general radiofrequency environment in one large urban area is given in Table IV.[13] The largest value of the power density at any of the three sites, 0.001 μW/cm.^{2}, is less than the median value for the broadcast frequency bands.

Power densities for continuous exposures are very low, certainly well below the 10,000 μW/cm.^{2} voluntary American National Standards Insti-

TABLE IV. TYPICAL URBAN RADAR ENVIRONMENTS IN SAN FRANCISCO, CALIFORNIA*

Location	*Number of radars detected*	*Average power density ($\mu W/cm.^2$)*
Mt. Diablo	8	0.000026
Palo Alto	10	0.00027
Bernal Heights	10	0.0011

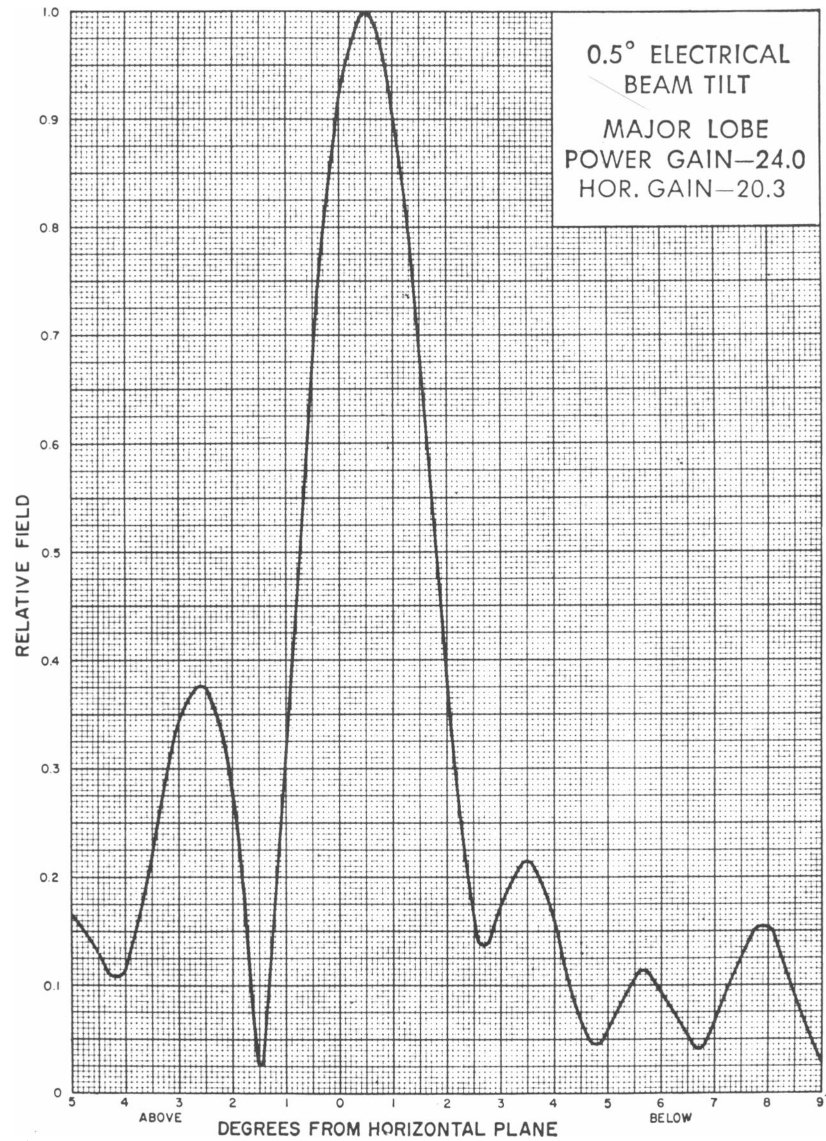
*Data from Tell[13]

tute standard for occupational exposure[14] and for more than 99% of the population less than the very conservative Soviet standards, i.e., 1 μW/cm.^{2} (2 V/m.) for frequencies between 30 and 300 MHz. and 5 μW/cm.^{2} for frequencies above 300 MHz.[15]

THE SPECIFIC SOURCE RADIOFREQUENCY ENVIRONMENT

Radiofrequency environments in the immediate vicinity of some specific sources, because of source power, proximity, or both, are usually dominated by the field of a single source that operates at a fixed or limited range of frequency. The measurement techniques used in the general radiofrequency environment can also be applied to specific sources, but hand-held, portable instruments are more commonly used.

A number of instruments have been developed for measurement of specific sources,[16-20] but to our knowledge no single, portable instrument covers the entire frequency range of interest. Almost all of the commonly used instruments are capable of measuring all three spatial components of either the electric or magnetic field and are so called "square-law" devices, i.e., their response is proportional to either the square of the electric or magnetic field, depending on whether an electric or magnetic field sensor is used. In the far-field, power density is proportional to the squared value of either of these quantities (see equations [1] and [2] on page 1022). Accordingly, the meter face is often labelled in power density, but power density is not measured directly and caution must be used in interpreting measurements made in near-field geometries. For frequencies above 300 MHz. an electric field sensor is usually used. For frequencies below 300 MHz. both electric and magnetic field sensors are used. It is important to note that for frequencies below 300 MHz. both the electric and magnetic fields should be measured if one is closer than a few wavelengths to the



Verticle pattern for a medium gain UHF antenna. Reproduced by permission from Tell, R. A.: *Reference Data for Radiofrequency Emission Hazard Analysis*. Technical Note ORP/SID-72-3. Washington, D.C., Environmental Protection Agency, 1972. Original source RCA Communications Division, Camden, N.J.

TABLE V. POWER DENSITY IN TWO TALL BUILDINGS THAT ARE LOCATED CLOSE TO FM BROADCAST ANTENNAS*

Location	*Power density ($\mu W/cm.^2$) FM*
One Biscayne Tower, Miami, Fla.	
Roof	148
Roof (shielded area)	134
38th Floor	97
34th Floor	62
30th Floor	5
26th Floor	7
Home Tower, San Diego, Calif.	
Roof	180
Roof	119
17th floor	0.2
10th floor	18

*Data from Tell and Hankin[22]

source. Most portable instruments have minimum sensitivities of about 20 $\mu W/cm.^2$ and, while they can be used to analyze most specific source environments, they are not sensitive enough to measure the submicrowatt per square centimeter levels found in the general radiofrequency environment.

Some recent advances in miniaturization make it feasible to measure electric fields in tissue or tissue-equivalent material.[21]

Broadcast sources. The antennas used for FM and for VHF- and UHF-TV broadcasting are highly directive. The energy is concentrated in a horizontal plane that passes through the antenna's center of radiation, which is approximately the geometrical center of the antenna. A typical antenna pattern for a medium gain UHF antenna is shown in the figure. With such antenna patterns, power density at high elevations close to the antenna can be considerably greater than at ground level. Measurements have been made in a limited number of tall buildings that either support broadcast antennas or are within a city block or so of another tall building that supports a broadcast antenna. Table V gives the results of measurements in two buildings located very close to FM broadcast antennas.[22] Note how the power density increases with height in the first building, just as would be predicted from such an antenna pattern as the one shown in the figure. Note also the inversion of power density with height in the

TABLE VI. POWER DENSITY IN TALL BUILDINGS LOCATED CLOSE TO FM AND TV BROADCAST ANTENNAS*

Location	Power density ($\mu W/cm.^2$) FM	TV
Empire State Building, New York City,		
86th floor observatory	15.2	
102nd floor observatory		
Near window	30.7	1.8
Near elevator	1.4	
World Trade Center, New York City		
107th floor observatory	0.1	1.1
Roof observatory	0.2	7.2
Pan Am Building, New York City		
54th floor	3.8	6.5
Sears Building, Chicago		
50th floor	32	34
Roof	201	29
Federal Building, Chicago		
39th floor	5.7	0.7
Milam Building, Houston		
47th floor	35.8	31.6

*Data from Tell and Hankin[22]

second building where windows above the 10th floor were covered with a reflective film to reduce solar heat loads. This transparent metallized film apparently also attenuates radio waves. The results of other measurements made in buildings are summarized in Table VI.[22] Note here that power density decreases as one moves away from windows, and, depending upon the type of sources that are close, both FM and TV bands can contribute. Exposure rates measured in buildings close to broadcast antennas range from less than 1 μW/cm.^{2} to 97 μW/cm.^{2} inside buildings or to 230 μW/cm.^{2} at an unshielded location on the roof of one building.[22]

Note that two circumstances are required to obtain these higher values: high elevation and proximity to the antenna of a high-power source. This is illustrated by the data in Table VII for measurements in Moffitt Hospital in San Francisco[23] and the Bank of Montreal Building in Toronto.[24] Moffitt Hospital is about 3,200 feet from Sutro tower, a 977-foot antenna tower that transmits signals for eight TV and four FM stations. The Bank of Montreal Building and the CN Tower are both located in downtown Toronto. The CN Tower rises 553 m. (1,814 ft.) above ground level and transmits signals for five TV and five FM stations. These data again show the variation with height that would be predicted from an antenna pattern

TABLE VII. POWER DENSITY IN TWO TALL BUILDINGS LOCATED FAR FROM FM AND TV BROADCAST ANTENNAS

Location	Power density ($\mu W/cm.^2$) FM	TV
Moffitt Hospital, San Francisco*		
Roof	1.048	0.450
15th floor solarium	0.114	0.101
15th floor	0.049	0.033
11th floor	0.002	0.001
6th floor (outside)	0.145	0.035
Bank of Montreal, Toronto†		TV‡
Roof, southeast corner	0.264	0.050
Roof, southwest corner	0.403	0.034
60th floor	0.216	0.013
45th floor	0.074	0.015
30th floor	0.009	0.001

*Data from Ruggera,[23] power density calculated from electric field strength values using equation [1].
†Data from Environmental Health Directorate[24]
‡The values in this column are only for channels 5 [77.25 MHz, 0.084 megawatts effective radiated power (MW-ERP)] and 9 [187.25 MHz, 0.28 MW-ERP] and does not include channels 19 [501.24 MHz, 1.08 MW-ERP], 25 [537.25 MHz, 2.14 MW-ERP], and 79 [861.25 MHz, 0.156 MW-ERP]. If power density were to scale directly with ERP the values in this column would be increased to about 13 times the given value.

such as the one in the figure. However, for these buildings which are located more distant from the antennas, power densities range from about 0.001 to 1 μW/cm.^{2}, values comparable to levels found at ground level. For Moffitt Hospital, a comparison of the sixth floor data when measurements were made outside of the building with the data for other floors gives a qualitative indication of the effect of building attenuation.

The study at Moffitt Hospital was undertaken because of concerns about electromagnetic interference with medical instrumentation. The subject of electromagnetic interference, though an important one, is not treated in this paper. Tell, Lambdin, and Mantiply have developed a technique to identify hospital locations potentially exposed to intense radio wave fields from nearby broadcast stations.[25]

Tower climbers who perform maintenance work on broadcast antenna towers, e.g., painting, light replacement, adjustments, etc., may be exposed to local fields near the antenna elements that are above the 40,000 V/m.^{2} value recommended by the American National Standards Institute.[14] The squared value of the electric field strength at various locations on an FM tower ranged between 7,200 and 678,000 V/m.^{2} in one study.[26]

Power densities near the base of FM towers are typically 1 to 10 μW/cm.^{2} (see Figure 8 in reference 7), but some FM antennas have a grating lobe coaxial with the tower in addition to the main lobe directed toward the horizon, shown in the figure, which can produce higher fields near the tower.[27,28] Power densities of 100 to 350 μW/cm.^{2} have been measured in areas accessible to transient foot traffic.[29] These levels fall off rapidly with distance from the antenna tower, but levels near a few residences may range from 50 to 100 μW/cm.^{2} Fields ranged between 1,000 and 7,000 μW/cm.^{2} at the base of an FM antenna tower in one study,[30] but values this high are not thought to be common; exposure-rates in open areas, i.e., not close to conducting structures, did not exceed 2,000 μW/cm.^{2}

Satellite communications and radar systems. Two other high power sources are satellite communications systems and the radars used for air-route surveillance. Satellite communications systems are continuous wave sources and radars are usually pulse modulated. A study done by the Electromagnetic Compatibility Analysis Center in 1972 identified 223 continuous wave sources with effective radiated powers greater than 1 megawatt (1 million watts) and 375 pulsed sources with peak effective radiated powers of 10 gigawatts (10 billion watts) or greater.[31] The power density in the main beam of these systems can be greater than 10,000 μW/cm.^{2} (10 mW/cm.^{2}).[32-34] However, as discussed above, the probability of being illuminated by the main beam of one of these sources is quite small.

Persons who live or work near high power sources, e.g., near airports or military bases, may be exposed to sidelobe or secondary radiation from systems with stationary or slowly moving antennas as well as from many types of radars with rapidly moving antennas. Calculated exposures fall into the range of 10 to 100 μW/cm.^{2} at distances up to one-half mile from some of these systems.[35] For high-power radars a combination of such mitigating factors as beam motion and antenna-elevation angle makes it unlikely that average power densities will exceed 50 μW/cm.^{2} at distances greater than one half mile from the source, at least in uncontrolled locations accessible to people.[35]

Low power radar. Three other radars in common use are weather radar in aircraft, navigational radar on small boats, and radar used to determine the speed of vehicles. Aircraft weather radar is located in the nose of aircraft under a microwave-transparent housing called a radome. Nor-

TABLE VIII. LOWER POWER RADAR SPECIFIC SOURCE ENVIRONMENTS

Source	*Distance (meters)*	*Power density ($\mu W/cm.^2$)*
Aircraft weather radar*	Radome surface	13,520
	1	<3,000
	10	<100
Marine radar†	Antenna's turning circle radius	50-250
Traffic radar‡	Antenna surface	170-400
	3	24
	30	0.2

*Data from Tell, Hankin, and Janes[36]
†Data from Peak, Conover, Herman, and Shuping[37]
‡Data from Hankin[38]

mally, they are not operated while the aircraft is on the ground. A study to determine the fields produced by these devices in the event they were inadvertently turned on while the aircraft was on the ground are summarized in Table VIII.[36] For the five radar-aircraft combinations studied, the power density was less than 10,000 μW/cm.^{2} everywhere except on the radome surface of one aircraft.

For marine radars, the average power density computed from measured values was less than 50 μW/cm.^{2} at the antenna's turning circle radius for all six units studied.[37] One of the units has an option for sector scanning, i.e., scan-arcs of less than 360 degrees. When operated in this mode, the average power density was about 250 μW/cm.^{2}

The radars used for measuring the speed of vehicles have transmitter powers of about 100 mW (0.1 watts). These devices are either hand-held or mounted on a vehicle. They are continuous wave rather than pulse modulated, and speed is determined from the Doppler frequency shifts of the returned signals. As shown in Table VIII, the maximum calculated power density for typical devices ranges from 170 to 400 μW/cm.^{2}, and decreases to less than 0.2 μW/cm.^{2} at 30 meters (about 100 ft.).[38]

Microwave radio relay systems. The microwave systems used for long distance communications usually have transmitter powers of five or 12 watts for frequencies of 4 and 6 GHz., respectively. A fully loaded station will have 12 transmitters at 4 GHz. or 8 transmitters for 6 GHz. operation yielding 60 watts and 96 watts, respectively, before taking account of wave-guide losses.[39] Power densities in the main beam are of the order of 1,000 μW/cm.^{2} (1 mW/cm.^{2}). The axis of the main beam is typically 200 feet above ground and power density falls off rapidly with distance from the beam axis. Maximum calculated values at ground level are less than 1 μW/cm.^{2}, and measured values are typically 1/10 to 1/100 of this, i.e., 0.1 to 0.01 μW/cm.^{2}, according to a recent report.[40]

Microwave ovens. Microwave ovens can be considered as low power devices if they meet the performance standard of the Food and Drug Administration, which specifies that under standard test conditions the oven, when new, may not leak more than 1,000 μW/cm.^{2} at any point 5 cm. from the oven.[41] This performance may degrade to 5,000 μW/cm.^{2} over the lifetime of the oven.[41] Simple inverse square calculations show that an oven leaking 5,000 μW/cm.^{2} at 5 cm. will produce levels of about 4 μW/cm.^{2} at six feet and 1 μW/cm.^{2} at 12 feet.

Personal radios. Most of the information on the specific source environments produced by personal radio devices is for systems mounted on vehicles or for hand-held walkie-talkies. Interpretation of these data is difficult because most measurements are made in the near-field and the fields are not uniform over volumes comparable to the size of humans. The absorption patterns for these complex near-fields may differ appreciably from those produced by far-field whole-body exposures, the absorption may be higher or lower, and the sites of maximum absorption may be different.[42-45] Further, the operation of these devices is intermittent and this variable duty factor complicates the determination of average exposure. Most measurements have been made in the near-field with electric field sensors and the measured values are properly expressed in V/m. As discussed above, power density is simply related to the electric and magnetic fields only in the far-field. To obtain power density in the near-field, the electric and magnetic fields and their respective phases should be measured. Some authors have defined an "equivalent" free field power density by assuming the impedance value for free space and calculating the power density according to equations [1] and [2]. However, when used in this manner, "equivalent" does not necessarily mean an equivalent heating power density. If one ignores this complication, then 10,000 μW/cm.^{2} is "equivalent" to 194 V/m. or 0.515 A/m. (The American National Standards Institute has rounded these numbers to 200 V/m. and 0.5 A/m., respectively[14].) Available data for radio-equipped vehicles are summarized in Table IX.[46-49] The values range from 2 to 1,350 V/m.

TABLE IX. ELECTRIC FIELD STRENGTH IN AND AROUND RADIO-EQUIPPED VEHICLES

Frequency (MHz)	*Power (watts)*	*Vehicle type*	*Field (V/m.)*	*Distance (m.)*	*Reference*
27.075	4	Sedan	2-7	1	46
27.12	4	Sedan	225-1350	0.05	47
27.12	4	Sedan	100-610	0.13	47
27.12	4	Sedan	21-60	0.6	47
27.61	80	Sedan	21-251	—	48
40.27	110	Sedan	10-190	—	48
40.27	110	Sedan	75-368	—	48
40.27	110	Semi	5-475	—	48
41.31	100	Compact	5-106	—	49
41.31	100	Pick-up	7-165	—	49
162.475	110	Sedan	8-201	—	48
164.45	60	Sedan	5-52	—	49
164.45	60	Sta. Wag.	5-64	—	49
164.45	60	Van	5-95	—	49

Only minimal data are available for the fields produced by hand-held walkie-talkies. In one study by Ruggera, the electric field 12 cm. from the antenna of a 2.5 watt hand-held unit had a maximum value of 205 V/m. and the maximum of the magnetic field was 0.9 A/m.[50] These maxima did not occur at the same point in space. The fields from these devices diminish rapidly with distance. The maximum field of 212 V/m. measured at about three inches from the antenna of a 1.8 watt, 164 MHz. hand-held unit was reduced to one tenth this value at a distance of 1 or 2 inches from the site of maximum exposure.[49]

Diathermy units. Both efficiency and leakage of microwave diathermy applicators have been the subjects of recent studies.[51,52] The results of the leakage studies are summarized in Table X. The measurements were made 5 cm. from the interface between a tissue-equivalent phantom and the applicator. Two treatment conditions were evaluated, the net power recommended by the manufacturer for lower back treatments and the power required to produce an absorption rate of 235 W/kg. The latter condition, based on the studies of Lehman et al.[53], is defined by the Bureau of Radiological Health as an "effective" treatment.[54] Under the test conditions, conventional applicators had leakage fields from two to nine times the 5,000 μW/cm.^{2} allowable leakage for microwave ovens. Leakage is

TABLE X. LEAKAGE FROM DIATHERMY APPLICATORS*

Applicator type	*Leakage (mW/cm.^{2})* Nominal†	Maximum‡
Burdick B″	10.4	35.5
Burdick E″	19.0	44.0
Transco‖	—	0.2

*Data from Bassen, Kantor, Ruggera, and Witters[52]
†Determined using power recommended by manufacturer for lower back treatments
‡Extrapolated for dose rate of 235 W/kg.
‖Contact applicator

considerably lower when using a newly developed contact applicator under the same test conditions.[52]

Electrosurgical units. The electrosurgical unit is an electronic knife used for both cutting and cauterizing. The principal frequency is about 2 MHz., but the device may emit frequencies up to 100 MHz. The electric and magnetic fields at 16 cm. from the electrode of two of these units are summarized in Table XI.[50]

Industrial radiofrequency sources. High-powered sources are used extensively in industry for heating, drying, and sealing. The data presented in Table XII are selected from a study of two synthetic fiber dryers used in the textile industry, an edge gluer used in the lumber industry, and seven heat sealers used in the plastics industry.[55] Recent unpublished work indicates that it is important to determine the actual frequency of operation of industrial sources; significant amounts of energy may be contained in the harmonics of the nominal frequency of the device.[56] This is particularly important since the absorption of radio waves in the 30 to 300 MHz. range is strongly dependent on frequency and exposure geometry.[10,11]

Other sources. Video display terminals have erroneously been implicated as sources of microwaves.[57] There are no microwave or radio wave power tubes in video display terminals. There may be some extremely minute emissions associated with oscillators in the device, but they cannot be detected with hand-held survey meters.[58] Extra-high-voltage transmission lines (345-765 kilovolts) have also been lumped into the category of radio wave and microwave sources. In periods of inclement weather, when water droplets or icicles on the line provide point sources for corona discharge, the discharge produces radiofrequency energy that may be of sufficient intensity to interfere with the reception of low-level radio signals, especially in the AM band, at locations near the line. Corona

TABLE XI. FIELD STRENGTHS AT 16 CM. FROM PROBE LEAD (CUTTING ELECTRODE) OF TWO ELECTROSURGICAL UNITS*

	Field strength			
	Solid state unit		Spark gap unit	
Operating mode	*E(V/m.)*	*H(A/m.)*†	*E(V/m.)*	*H(A/m.)*†
Cutting (50% power)				
Open circuit	605	0.22	300	0.10
Normal cutting	210	0.60	250	0.56
Arcing	350	0.22	260	0.17
Coagulation				
Open circuit	620	0.06	300	0.41
Normal coagulation	250	0.16	140	0.10
Arcing	300	0.12	120	0.08
Hemostasis (50% power)				
Open circuit	680	0.28	690	0.43
Normal cutting	270	0.40	300	0.56
Arcing	350	0.27	300	0.58
Hemostasis (100% power)				
Open circuit	1,000	0.71	630	0.39
Normal cutting	250	0.46	200	0.40
Arcing	350	0.30	600	0.40

*Data from Ruggera[50]
†Rounded to two significant figures

discharge may also be caused by line irregularities, dust, bird droppings, etc. Loose connections between the line and insulators can lead to arcing, so-called gap discharge, that is also a source of radiofrequency interference. Except for corona and gap discharge, high voltage power lines are not radio wave or microwave sources. Quasistatic, nonradiating electric fields at midspan range between 4 and 12 kilovolts per meter (kV/m.) on the right-of-way and between 1 and 3 kV/m. at the edge of the right-of-way.[59] For 500 kV lines with 595 amperes in each of the three phases, magnetic flux at ground level is typically about 0.1 gauss (0.1×10^{-4} A/m.).[60] A number of reviews on the health and environmental impact of extra-high-voltage lines and other extremely-low-frequency sources are available.[61-66]

SUMMARY AND CONCLUSIONS

The multisource, multifrequency, general radiofrequency environment is dominated by low-level radio and television transmission. Microwave radio relays, low-power radars, mobile communications systems, and microwave ovens make almost negligible contributions to the general radio-

TABLE XII. ELECTRIC AND MAGNETIC FIELDS AT OPERATOR POSITIONS NEAR INDUSTRIAL RADIOFREQUENCY SOURCES

Source	Power (kW)	Frequency (MHz.)	Field strength* Electric (V/m.)	Field strength* Magnetic (A/m.)
Fiber dryer	20	41	319	13.2
Glue dryer	20	27	221	1.0
Heat sealer	10	15	831	0.5
Heat sealer	2	22	493	12.1
Heat sealer	4	30	973	0.4

*Average of two values given in Conover et al.[55]

frequency environment. The largest multisource radar field measured in the general environment of one urban area was less than the median value for the broadcast band (54-900 MHz.). It is estimated that most of the population (over 99%) is continuously exposed to levels less than 1 μW/cm.^{2} This level is well below the current American National Standards Institute standard of 10,000 μW/cm.^{2} and below the extremely conservative standards of the U.S.S.R. (2 V/m. = 1 μW/cm.^{2} for frequencies between 30 and 300 MHz., 5 μW/cm.^{2} for frequencies between 300 MHz. and 300 GHz.[15]).

The specific source environment for most broadcast sources is below 100 μW/cm.^{2} The only fields in excess of this value occur on the antenna towers, in the immediate vicinity of the base of some FM antenna towers, and on the roofs of tall buildings that are located within a city block or so of FM and TV broadcast antennas. When considering other high power sources such as radars and satellite communications systems, the potential for exposure of persons to obviously high levels of radiation (10,000 μW/cm.^{2} or greater) is small. However, the population exposed to specific source environments greater than 1 μW/cm.^{2}, though small, remains to be determined and is the subject of ongoing studies.

Intermittent, partial body exposures to high levels can and do occur. Leakage fields from medical diathermy units, electrosurgical units, industrial sources, and the fields very near to the antennas of mobile communications equipment have been measured to be in excess of 200 V/m. and 0.5 A/m., the electric and magnetic field "equivalents" of a far-field power density of 10,000 μW/cm.^{2} Interpretation of the impact of these near-field exposures is difficult, and the difficulty is confounded by intermittent operation and partial body exposure. Better knowledge of the rates and sites of energy deposition is needed before near-field exposures can be meaningfully compared to the far-field exposure data that form the basis for current standards.

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GENERAL DISCUSSION: SESSION I*

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OM P. GANDHI, Sc.D., DAVID E. JANES, JR.

DR. NORMAN SIMON (Mt. Sinai School of Medicine): A number of questions concern us as physicians who have an obligation to advise patients as well as, of course, to the more important problem of public health. We know how to measure ionizing radiation and have come here to learn how to measure nonionizing radiation. We understand the complexities of this. Yet we find that comments were made about the role of flat reflectors and we wonder how that affects the dose exposure to the housewife in microwave ovens. We wonder how broad that beam is from the antennae of TV and from radar, which are supposed to miss the earth and go over it and thus not expose the people at the beaches. We hear that one gets measurable amounts of microwave radiation. We are not sure how significant they are.

We heard about measurement devices. In the back of *House and Gardens* magazine we see that one can buy a detector of microwaves to make sure that one's oven is safe. What are those? Are they as reproducible, accurate, and reliable as is a film badge for ionizing radiation (and that is not particularly good)? Or should they not be used at all? In fact, how does the worried housewife and the worried physician answer that question of how safe is the microwave oven? Whom do people call to measure microwaves and what is the responsibility nowadays of the supplier of such an oven?

What is the level of nonionizing radiation in the research or therapy unit in a hospital where microwave radiation is used for its thermal effects or in the laboratory? How do we know the power density of our own neighborhoods and is it of any significance?

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MR. DAVID JANES: In terms of hospital environments, some people out on the West Coast are trying to establish standards for internal hospital operations that are on the volt per meter. I think the leakage field for the microwave diathermy applicator, as I indicated, was in the order of 35 to 40 mW/cm.^{2} That is measured right up on the surface of the device. At 8 to 10 to 12, to 14, 15 feet I would expect that to be down to microwatt per square centimeter levels at the time that the device is on. One must be a little bit concerned about the duty factor in many of these devices, that is, how often they are on. One can encounter fields of 200 volts per meter to 1,000 volts per meter around electrosurgical units at the time they are on.

If the microwave oven in the home meets the Food and Drug Administration's leakage standards, that is, doesn't exceed the maximum value of 5 mW/cm.^{2}, then at the time the oven is on one can expect fields below 4 μW/cm.^{2} at around six feet and below 1 μW/cm.^{2} at 12 feet.

The other question you raised is where my heart lies and where we spend a lot of time. We have now made measurements of the general radiofrequency environment in 15 cities. Those measurements have been made at more than 400 sites. We have some 20,000 distance source measurement pairs. In that general environment one is not exposed to very much at all. We are talking about nanowatts per square centimeter, 0.005, perhaps. I put up the 15 city data to illustrate that it doesn't make much difference once one gets away from median values. We are going to quit doing these kinds of surveys because another city would not tell us much more. One city seems to be pretty much like the other. In general, most of the population is exposed to levels less than 1 μW/cm.^{2}

I talked about how skewed that distribution was to low values, and one of the things that concerned us a great deal when we set up that study was population mobility. These figures apply to where people live. They are based on census data. Actually, they are based on a centroid of a census enumeration district, which accounts for about 800 people. So it is the exposure one would find if one could find the centroid of one's census enumeration district and spent all of one's time there. But with this distribution skewed to such low values, mobility doesn't mean much. I would say that in general one moves from one low area to another. I view it as a sort of a general radiofrequency environment out there, with relatively low levels. Embedded in that are some specific sources where one gets relatively higher levels and the level that one gets depends on two things: the closest distance of approach and the source power. The distance of approach can be in terms of inches for a hand-held walkie-talkie and maybe as much as a half a mile for a high powered radar.

DR. JOHN OSEPCHUK: I would like to remind everybody that everything is a function of frequency. It is really important to know what frequency one is at. But Dr. Simon mentioned something about reflector effects from a microwave oven. I want Dr. Gandhi to discuss the reflector effect and what that has to do with the general environment. When one has a very localized environment, what meaning does it have if one has a diverging wave like that from a microwave oven?

DR. OM P. GANDHI: I deliberately did not comment on the near fields such as those emanating from the microwave oven. I did mention that we have had a preliminary look at the problem and our knowledge to date is as follows: if one is in direct contact, if one puts one's hand on a leaking oven door, one may couple almost all of the electric fields that are coming out of the microwave oven. One removes one's hand from there and starts moving away. By the time one is about 10 or 15 cm. away from the leaking oven door there is a great deal of reduction in the amount of energy coupled due to two factors. One, the field is diminishing rapidly because of spreading. Second, the coupling into the tissue diminishes rapidly for the fields that do exist there. Depending on the frequency, say 2,450 MHz., the electric field that one can couple into one's hand or whatever part of the tissue is closest diminishes from 100% coupling if one had his hand on the door to about 25% of the electric field in noncontact situations. Therefore, by the time one is 10 or 15 cm. away one is diminishing the E^2 value that one can couple to no more than 6% of the E^2 that exists at that location. Consequently, in near-field, noncontact situations, by the time one is a few feet away the energy density itself is very little.

DR. LEONARD SOLON (New York City Department of Health): Mr. Janes, several individuals have suggested as an epidemiologically interesting group the rather substantial number of ham operators, ARRL members, etc. that operate their units. Have your measurements included any measurements which would identify the field levels around those units as far as the operators are concerned or their immediate proximity?

MR. JANES: Dr. Solon, we could put something like that together for you. We have some things. But I didn't come prepared to discuss it and I don't recall the results at this time. Those devices are essentially long wire antennas and they are limited to a kilowatt at the final amplifier stage. I won't guess what field levels are inside the ham shack. Ric Tell, who is on our staff, is a ham and he has assembled some data about his own exposure. So we have it. I am just sorry I cannot share it with you.

DR. LOUIS SLESIN (Natural Resources Defense Council): Mr. Janes, you were showing that the antilevels in urban areas are a few feet off the ground, six to eight feet. Would you comment on the kinds of readings you have found in tall buildings such as the Empire State Building and perhaps detail what the Environmental Protection Agency is going to be doing in the future in terms of getting more data on high points?

MR. JANES: I showed a slide that had an antenna pattern on it. That is what accounts for greater exposures at higher elevations. One must be reasonably close to an antenna and on the upper floors of tall buildings to obtain these levels. One has to get high enough essentially to look into the center of radiation of the antenna itself. I ran through a few numbers for you. I shall give them again. Roughly, one sees power densities on the order of 1 to 10 $mW/cm.^2$ In Chicago I think we saw as much as 67. There is a building in Miami where we measured 100. These are inside the building, up against the windows. They are not done with hand-held probes but with a spectrum analyzer and some tuned antennas. The antennas are large and must be rotated through three ortogonal axes to obtain the total field strength. So one doesn't map rooms with that kind of a system. We have underway some computer-based studies to see if we can identify station-tall building pairs, that is, to see if we can come up with an inventory of stations that are close to tall buildings. If we are successful in that, we shall try to go out and look at what that population of building exposure looks like.

DR. DEBORAH WALLACE (New York State Power Authority): Are there natural sources of microwave and radiofrequency radiation that might be equated to your measurements in the general environment or which measure up to the levels of microwave communication towers?

DR. OSEPCHUK: In my paper there is a benchmark diagram relevant to your question. The microwave or radiofrequency radiations go up to 300 gigahertz and it is a very straightforward calculation that the tail of black-body radiation, the thermal radiation from the human body, of all the energy below 300 gigahertz, is around 0.3 $\mu W/cm.^2$ Most of that energy is near 300 gigahertz, and if it is a hotter body it will be even higher. Now, if one asks how much energy from a hot body is below one gigahertz, it is trivial. It would be several orders of magnitude smaller than that. If one asks what the microwave flux from the sun is in that same range below 300 gigahertz, it is very low. As a matter of fact, that is one reason why this region around 1 gigahertz is a very interesting region for radioastronomers. It is a very quiet region. At the higher frequencies and the lower frequencies there are more natural noise sources. But in the microwave region, as far as I know, among the natural sources the biggest thing is one's own body.

MISS JEAN ST. GERMAIN (Memorial Sloan-Kettering Cancer Center): Do you have any measurement of RFP—accelerators or devices such as that?

MR. JANES: No, I don't. If you are interested in pursuing that, I would direct an inquiry to either David Conover or Dr. Parr at the National Institutes of Occupational Safety and Health in Cincinnati. That is not really a general environment. So we haven't made any measurements of our own sources like that.

DR. JAMES FRAZER (University of Texas): You might come up with something on the order of 10 μW at operating stages. As one gets up near the tubes where one is not supposed to be, it can get up around 11 mW, but if one stays where one is supposed to be one won't see those kinds of fields.

DR. WORGUL: What frequency was that?

DR. FRAZER: I think that one operates at 2,800 megahertz.

BIOMEDICAL EFFECTS OF MICROWAVE RADIATION*

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IN reviewing and updating our knowledge of the biomedical effects of microwave radiation, I am reminded of past meetings with the same goal: the Triservice meetings—Richmond, Warsaw, Boulder, Amherst, Airlie, and several others.

Nearly three decades ago our major concerns seemed to center about cataractogenesis and the distinction between thermal and nonthermal effects. And while these concerns are still of intense current interest, we have now added such concepts as frequency windows, intensity windows, special modulation effects, and the critical importance of body size and shape in determining the absorption of radiofrequency radiation of specified frequency and polarization. Increased attention is now given to immunologic, behavioral, and central nervous system effects, and the lingering but largely unresolved questions about long-term low level effects. To say that these older problems have been solved or that adequate attention is now given to them would be a misstatement of fact.

Many earlier studies attempt to correlate exposure levels with observed biological effects. It was, and unfortunately still is, customary to express environmental levels of radiation in terms of average power density (W/m.$^{-2}$ or mW/cm.$^{-2}$) or "equivalent far-field" average power density, with little attention to the specification of waveform, polarization, reflections, scattering, geometry of the body being irradiated, or whether exposure conditions are in the near or far-field of the radiating source. Specification of exposure levels without some qualification pertaining to the aforementioned factors should be considered obsolete practice.

An important result of our present knowledge is the realization that the usefulness of most studies published more than a decade ago is open to serious question.

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OCULAR EFFECTS OF MICROWAVE RADIATION*

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In 1948 two groups of investigators[1,2] reported independently and almost coincidentally that when the eyes of rabbits or dogs were exposed to sufficient microwave radiation, opacities subsequently developed in the crystalline lens. Both groups employed continuous wave radiation at a frequency of 2.45 GHz. with a wave length of 12.3 cm. In the 30 years since that initial discovery, this phenomenon has been extensively investigated in numerous laboratories and we now have a substantial body of information concerning it. However, we have yet to identify the site and the manner of interaction between microwaves and ocular tissues which provide the mechanism for cataractogenesis.

During the same period the use of microwaves has increased at an ever accelerating pace. Because of them, our ships and planes are guided by radar; the human voice is relayed across the continent and, via satellites in space, spans the oceans; events occur in distant lands and we see them simultaneously on our television screens. Food is cooked rapidly on a commercial scale and in the home kitchen. Sales of domestic microwave ovens in 1978 were greater than those of conventional ranges. Industrial uses include the quick drying of paints, inks, lumber, plywood and veneers, the curing of synthetic rubber, and the controlling of insect infestation of stored grain. In medicine, microwave diathermy units relieve sore muscles and aching joints with their deep heat therapy, and microwaves quickly reheat the blood after cryogenic surgery. Their use in enhancing the effects of ionizing radiation on neoplasms is under extensive study.

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During the past decade, the ever expanding use of microwave radiation has increased public awareness without a commensurate increase in public knowledge and understanding. To many people, the notion that microwaves are radiation and all radiation is dangerous is accepted as established; the term ''radiation'' has acquired a bad image, deserved or not. Microwaves, representing a small part of the broad spectrum of electromagnetic radiation, have become the subject of a very considerable amount of misinformation disseminated by the public media. Radio and television programs tell of hazards to our health inherent in microwaves; newspapers and magazines similarly alarm readers with articles emphasizing their hidden dangers. That their authors in too many cases possess little basic knowledge of the subject is obvious to only a few. A book has been published purporting to reveal a conspiracy by government and industry to prevent the public from gaining knowledge of the hidden dangers of microwaves.[3]

Following the discovery that the predominant permanent effect on the eye from exposure to microwave radiation was the development of opacities in the lens, investigators early turned their attention to the question of how much microwave radiation was necessary and how long it had to act on the eye to induce formation of an opacity.[4-7] The approach was straightforward. The experimental animal, usually a New Zealand White rabbit, was anesthetized and one eye was placed for a specific period of time in a microwave field which had been measured for its power density, i.e., the electric field power flowing through the area to be occupied by the target. In most instances the microwave frequency was 2.45 GHz., continuous wave. Following irradiation, the eyes were examined at intervals by ophthalmoscope, slit-lamp biomicroscope, or both for evidence of change. The nonirradiated eye served as the control. The earliest positive reaction to such radiation is the appearance, within 24 to 48 hours, of a narrow translucent or milky band in the posterior cortex of the lens just under the capsule. It can be seen only by slit-lamp examination with an angled beam. The band extends no farther than the lens equator; sometimes it is doubled, with a clear band of cortex intervening.[5] If the reaction is minimal, no further change occurs and the cortical banding disappears within a few days. Otherwise it is typically followed, two to four days postirradiation, by small granules on or along the horizontal line of the posterior lens suture. In some cases the granules are clustered and in others uniformly dispersed in the posterior subcapsular cortex. With a more extensive reaction, a greater number of granules is added over a larger area within the next few days and small vesicles may develop. These early changes may progress from day to day and become frank circumscribed or diffuse cataracts. They may take on a fibrillar, cottony appearance, particularly in a diffuse cataract, which involves a more extensive area of posterior cortex. These lens changes remain as permanent microwave effects.

Certain other ocular reactions also occur but are transient in nature and differ in severity according to the power and duration of the exposure. They include swelling and chemosis of bulbar and palpebral conjuctivae, pupillary constriction, hyperemia of iris and limbal vessels, and vitreous floaters and filaments.

If a number of such single exposures are made and their results plotted in terms of duration of exposure against microwave power density incident on the target, one obtains a cataractogenic threshold curve in which the two factors are inversely related. In other words, the lower the incident power density, the longer the exposure required to induce cataracts. Several such curves have been published but, although they all have a hyperbolic form, they tend to differ with respect to specific power levels. This is not surprising because a variety of techniques was employed for measuring power densities. In addition, the radiation source commonly used was a dipole antenna backed by a corner reflector, with the eye only 5 cm. from it. The field was therefore a near-zone one, in which there are inherent difficulties in assessing the microwave power. The presence in the field of a plastic animal restrainer or a head holder may cause reflections which perturb the field and thus profoundly alter measurement of the power density.

A cataractogenic threshold curve identified not only those time and power combinations which would cause development of opacities in the lens but also those which would not. It thus became possible to test the question of whether there could be a cumulative effect from repeated exposures of the eye to a subthreshold dose which, when applied only once, does no evident harm. Such experiments were performed and did, indeed, demonstrate that irradiations which had no apparent effects when experienced a single time could inflict permanent damage when repeated daily or even weekly.[8,9]

In another series of experiments, nonanesthetized mature New Zealand White rabbits were placed in an anechoic chamber and their right eyes were irradiated at a distance of 5 cm. from a dipole antenna at 2.45 GHz.,

TABLE I. LENS OPACITIES RESULTING FROM CONSECUTIVE DAILY ONE HOUR EXPOSURES OF THE RABBIT EYE TO 2.45 GHz. C.W. RADIATION

Power density (mW/cm.^{2})	*Number of animals*	*Number of exposures*	*Positive response*	
			Number of animals	*%*
75	10	20	0	0
120	9	20-24	1	11
135	10	20	1	10
150	10	18-32	4	40
165	10	21-30	4	40
180	10	13-20	8	80

TABLE II. LENS RESPONSE RESULTING FROM A SINGLE CONTINUOUS EXPOSURE OF RIGHT EYE OF RABBIT TO 2.45 GHz. C.W. RADIATION AT 180 mW/cm.^{2} POWER DENSITY

Number of animals	*Exposure duration (hours)*	*Right eye*		*Left eye*		*Postirradiation observation period (days)*
		Opacity	*No change*	*Opacity*	*No change*	
7	1	0	7	0	7	30-324
1	1.75	0	1	0	1	20
2	2	0	2	0	2	11
1	2.5	0	1	0	1	10
2	3	0	2	0	2	343, 363
1	3.5	0	1	0	1	340
1	4	1*	0	0	1	348
1	4.5	1†	0	0	1	329
1	5.5	0	1	0	1	315

*Small central opacity after 137 days; no change thereafter.
†Small central opacity after 173 days; no change thereafter.

continuous wave, one hour daily for 20 consecutive days. The aim was to find the lowest power level that would consistently induce lens opacities. The results of 59 such experiments are given in Table I.

It should be pointed out that this table and Table II correct the power density measurements originally published.[10] They had been made with a Narda Model 8100 electromagnetic radiation survey meter[11] placed with its sensing probe in the exact position to be occupied by the cornea of the eye during exposure. We subsequently learned that in the near-zone field of the particular type of antenna used there is a radial component to which the probe does not respond. When measured with a Narda isotropic broad-band instrument,[12] values for power density were 50% higher. We have therefore corrected the tables.

In only four out of 10 experiments, each at the 150 and 165 mW/cm.^{2}

levels, did lens opacities develop, but when the power was raised to 180 mW/cm.^{2}, opacities developed in eight of 10 animals. To be assured that this one-hour exposure at 180 mW/cm.^{2} was indeed a subthreshold one, seven animals were irradiated and none developed an opacity (Table II). Ten more animals were similarly irradiated under anesthesia, but for periods up to 5 1/2 hours. Small central opacities, appearing only after several months, developed in two of the animals exposed for four and 4 1/2 hours, respectively.

It appears that so far as the rabbit eye is concerned, the maximal safe exposure level of 10 mW/cm.^{2} recommended by the American National Standards Institute and generally accepted by most of the Western world, is satisfactory. In our experience, an incident power density of 250 mW/cm.^{2} acting on the eye for 35 to 40 minutes is required for cataract induction by a single exposure. As noted above, multiple exposures at 180 mW/cm.^{2}, each of one hour's duration and applied daily for 20 consecutive days, also are cataractogenic. It must be pointed out, however, that there are serious difficulties in attempting to extrapolate experimental findings from the rabbit to man. Right now we can speak with authority only for the rabbit.

We do not know precisely what takes place in the irradiated lens that leads to formation of opacities, but we have a few hints. Biochemical changes in lenses exposed to a cataractogenic dose were reported by Merola and Kinoshita[13] and Kinoshita et al.[14] They removed the lenses of both eyes at various intervals after cataractogenic exposure of the right eye. The earliest detectable change was a decrease of approximately 23% in the ascorbic acid level of the irradiated lens. This change was observed in lenses removed 18 hours after irradiation, but was not evident at a half hour or at six hours. The latter fact seemed to eliminate the possibility that the reduction was due to an intraocular temperature rise during irradiation. The ascorbic acid level of the aqueous humor was not changed and, when isolated lenses that had not been irradiated were heated to the same temperature and for the same period of time as the microwave irradiated lenses, their ascorbic acid content did not change.

Kinoshita et al.[14] noted that during the 18 hour postirradiation period, the lens glutathione level did not change, an observation of interest because in cataracts caused by x rays, glutathione decreases before any change in ascorbic acid. The early drop in the ascorbic acid level of the lens seems to be the distinguishing feature of microwave cataracts.

Weiter et al.,[15] irradiating rabbit lenses grown in culture media, found a significant decrease in ascorbic acid. No differences in ascorbic acid levels were observed when control lenses were subjected to the same time and temperature conditions as irradiated lenses. Their conclusion was that the microwave heating effect caused the decrease in ascorbic acid.

The mammalian lens consists of concentric layers of elongate lens fibers enclosed in an elastic lens capsule. Under the capsule's anterior surface only is a single layer of cells which constitutes the lens epithelium. During the life of the lens some of these cells multiply by mitotic division, gradually migrate to the lens equator and there undergo differentiation and growth to become new lens fibers. The epithelium, therefore, is a metabolically active layer. Present information suggests that it may be the primary site of action of microwaves.

Van Ummersen and Cogan,[16] using an autoradiographic technique, studied the lens epithelium in rabbit eyes at intervals ranging from six hours to one month after cataractogenic irradiation of the right eye. One hour before each animal was to be killed, it was anesthetized and 4 microcuries of tritiated thymidine injected into the anterior chamber of each eye. This radioactive form of thymine is taken up by any cell which is actively synthesizing deoxyribonucleic acid in preparing for mitotic division. After an hour the animal was killed, the lenses removed and histologically preserved, and the epithelium and overlying capsule were peeled from the anterior lens surface and affixed to a glass slide. The slide was dipped in photographic emulsion in the dark and left in darkness for a month, after which the emulsion was photographically developed. This brought about the deposition of small aggregates of silver grains on the nucleus of any cell which had taken up the tritiated thymidine. These labelled cells and those already undergoing mitosis were then counted in every pair of lenses. The resultant data gave a statistical basis to compare the premitotic and mitotic activity of the epithelium in irradiated and control lenses.

Van Ummersen and Cogan found that the characteristic response of the irradiated epithelium was a marked suppression of both DNA synthesis and mitosis. This was evident as early as six hours postirradiation and was still clearly shown at five days. After a week the suppression of DNA synthesis and mitosis gradually diminished and by two weeks these activities were proceeding at the same rate as in the control eye. At the end of a month the irradiated lenses had a slightly accelerated rate, as if there were some overcompensation. The authors noted that the sequence of events in the irradiated lenses closely paralleled that shown by the lens epithelium after an eye has been exposed to ionizing radiation.

A study of the continuity of events in the rabbit lens during development of a microwave cataract has been made in our laboratory.[17] The right eyes of New Zealand White rabbits were exposed to a cataractogenic dose of microwave radiation at 2.45 GHz., continuous wave. At postirradiation intervals ranging from 12 hours to 123 days the animals were killed, both eyes were removed, and the lenses were preserved and prepared for histological study. Fifty-one lenses were studied in serial section for histopathological change, and sectioned lenses of the nonirradiated left eye served as control preparations.

As early as 18 hours postirradiation, changes can be observed. The posterior ends of those lens fibers subjacent to the posterior lens capsule swell and there is a distortion of the pattern of epithelial cells at the lens equator, cells which would normally differentiate into new lens fibers becoming arranged in a whorl or a rosette. During the second and third days postirradiation these changes progress. Posterior subcapsular fibers up to a depth of 75μm. from the capsule may develop within their cytoplasm myriads of microscopic vesicles and small cysts may also occur in the subcapsular cortex. These effects probably represent hydropic changes in the lens and may constitute an initial response to the thermal insult. Another feature observed at this time is the swelling into spherical shape of some of the epithelial cells at the equator. This transformation to so-called "balloon cells" has previously been described as a characteristic change following exposure of the eye to ionizing radiation.[18] Also in the equatorial region, the orderly bow-shaped pattern formed by the nuclei of differentiating new lens fibers may become distorted and shift posteriorly.

At four days postirradiation a more extensive response of the equatorial epithelium takes place as a burst of mitotic activity and migration of proliferated cells posteriorly under the lens capsule so that a double-layered epithelium may form where normally there should be no epithelial cells at all. In some cases there was a second aberrant layer of nuclei, situated more deeply in the posterior cortex. This effect on the equatorial epithelial cells, occurring only after four days, may be a response to the radiation itself rather than to the initial resonant heating.

It may be related to the inhibition of DNA synthesis in the anterior epithelium of the lens during this period, as reported by Van Ummersen and Cogan.[16] Areas of degenerated lens fibers in addition to swollen fibers are evident at four days and there may be numerous cysts, some of them containing a granular precipitate. At this stage in the development of a microwave cataract, the most notable feature is the large number of cell divisions and the posterior migration of cells, heretofore considered characteristic of cataracts induced by ionizing radiation.[18].

By the sixth day postirradiation there are usually many more "balloon cells," which probably represent abortive attempts of epithelial cells to undergo their normal differentiation into new lens fibers. Mitotic activity is still present and the aberrent posterior epithelium may be three cell layers thick or may occur in isolated nests or patches. Distended lens fibers and relatively large cysts are present in the posterior cortex. No mitoses were observed in lenses later than six days postirradiation but the degenerative changes already in progress continue. Sections of lenses from one to five weeks postirradiation exhibit balloon cells, swollen fibers, epithelial cells displaced to abnormal sites, vesicles and cysts, and denatured and liquifying fibers. Many of these histopathological changes remain evident in a lens removed 123 days after cataractogenic irradiation. They are responsible for the lens opacification observed *in vivo* by ophthalmoscopic or slit-lamp examination.

These studies suggest that although the initial clouding of the posterior layers of the lens cortex may be due to microwave heating, the definitive opacities result from changes induced in the equatorial epithelial cells by microwaves. These changes more nearly resemble those caused by exposure of the eye to ionizing radiation than those caused by heat.

Throughout this study careful measurements were made of capsule thickness in sections of the irradiated and the nonirradiated eyes. No significant differences could be identified. The thickening and roughening of the posterior capsule which Zaret[19,20] reported in human cataracts alleged to be of microwave origin does not occur in cataracts known to have been caused by microwaves in the rabbit.

Knowledge of the effect of microwaves on the human eye is disappointingly meager. Because experiments of this nature cannot be performed on the human, we must depend for our information upon accidental or inadvertent occupational exposure of the eye to this kind of radiation or to the results of epidemiologic studies on large groups of persons, many of whom had a considerable probability of being exposed to microwaves while others did not. Results of such surveys have in general been inconclusive.

SUMMARY

Thirty years ago two groups of investigators independently found that when the eyes of laboratory animals were exposed to microwave radiation, opacities might subsequently develop in the lens.

A point early investigated in rabbits was how much microwave radiation was necessary in a single dose and how long it had to act on the eye to induce a lens opacity. Resulting cataractogenic threshold curves were similar in shape but varied due to differences in microwave frequency and in the manner of measuring the power of the microwave field, and because almost anything placed in the field altered that field merely by its presence.

Having determined the cataractogenic threshold for a single dose, it was found that a microwave dose incapable of producing apparent effects when applied only once might cause a lens opacity if applied repeatedly at regular intervals.

The earliest identifiable effect of microwaves on the eye occurs within 18 hours, a decrease of more than 20% in the concentration of ascorbic acid in the lens. Radioautographic studies have demonstrated that a single cataractogenic exposure inhibits DNA synthesis and mitosis in lens epithelial cells; recovery does not begin until the fifth day postirradiation, and takes 10 days to two weeks.

Histopathological studies of microwave cataract development in the rabbit eye reveal that the primary change occurs in the lens epithelium. Irradiated epithelial cells at the lens equator migrate posteriorly under the capsule, meanwhile undergoing mitotic cell division, so that a posterior epithelial layer becomes aberrantly formed. Large spherical or ovoid "balloon cells" appear around the sixth day at the equator and in the posterior subcapsular cortex. In many cells small vesicles accumulate and coalesce to form cystic cells which may unite with others and form larger cystic spaces. Measurement of the thickness of the posterior capsule reveals no significant differences between irradiated and nonirradiated lenses.

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BEHAVIORAL AND PSYCHOLOGICAL EFFECTS OF MICROWAVE RADIATION*

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MY title may appear redundant, but I separate the subjective human psyche from the more objective goings on associated with behavior. Microwaves and other radiofrequency radiations of the electromagnetic spectrum can have highly predictable effects on behavior at modest and even low levels of irradiation. Introduction of weak fields into sensitive tissues promotes *bona fide* physiological reactions that give rise to changes in behavior. A more subjective and indeterminate class of behavioral reactions is also discussed, with emphasis on *neurasthenia,* a reversible syndrome akin to mild depression. The syndrome has been attributed to weak microwave fields, but an etiological connection has yet to be demonstrated or refuted. A third class of reactions, afflictions provoked in the human psyche by microwave radiation as a semantic agent, are not borne of physical forces in the usual sense of the word but are *imagined* effects of radiofrequency radiation, which certainly have consequences for human behavior, but their origin is in the workings of the scientifically untutored or overly suggestible mind.

Any discussion of imagined effects will inevitably focus on distortions and unsupportable speculations that have received much play in the popular media. A good case in point is the statement that microwave ovens emit ionizing radiations, which appeared in *Time* (April 9, 1979) and *U.S.*

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News and World Report (April 16, 1979) shortly after the accident at the Three Mile Island nuclear facility in Pennsylvania. The reader should not draw the conclusion that mine is a *lèse majesté* or condemnation of those members of the Fourth Estate who have fostered the public's belief in nonexistent ills and insults of radiofrequency radiation. If the proximal stimulus of public unrest largely lies in the press and television, the ultimate cause is the failure of radiobiological scientists and technologists to communicate adequately their knowledge to the purveyors of public information. The lines of communication between expert and expositor are indeed poor.

Veridical Behavioral Reactions

Experimental studies. More than 5,000 reports of biological effects have appeared in the literature of radiofrequency radiations,[1,2] most based on experimental exposures of small animals to fields in the microwave spectrum (300 MHz.-300 GHz.) or at lower radio frequencies, and a substantial number relate in whole or in part to behavioral reactions. Most of the scientific reports from the United States are based on studies in which exposures were of short (minutes to hours) duration to highly intense fields well in excess of 10 mW/cm.^{2} The "hard" behavioral data that have emerged are therefore associated with acute effects and include (in approximate order of decreasing strength of fields) convulsive activity, work stoppage, work decrement, decreased endurance, perception of the field, and aversive behavior.

Electrical units and concepts. I shall characterize the data on acute behavioral effects in terms of electrical units such as mW/cm.^{2}, J/g., and mW/g. Appendix A and its associated tables define and illustrate the more commonly used electrical conventions and summarizes some basic physical concepts relevant to the quantitation of radiofrequency fields in biological systems. The reader is urged to review the appendix before proceeding further if he finds himself in unfamiliar territory.

Convulsions. *Grand-mal* seizures are induced by intense irradiation by radiofrequency energy and probably result from high body temperatures; they have been observed within 30 minutes in mice and rats under standard environmental conditions at power-density thresholds that cover a considerable range—from less than 5 to more than 500 mW/cm.^{2}—depending on the geometrical and electrical factors that determine the efficiency with which such radiation is coupled to the body.[3] While the power densities associated with convulsive activity are highly variable, the whole-body averaged dose of energy is not.[4] Under standard environmental conditions, the threshold convulsive dose lies between 22 and 35 J/g. of body mass and holds for exposures ranging from less than a millisecond[5] to 15 minutes.[6] While energy-dose thresholds of convulsions are highly stable, they are quite sensitive to basal body temperature at initiation of irradiation and to environmental variables, especially those of ambient temperature and air velocity.[4,6,7] The critical factor is core temperature; when elevated to a level near 43°C. the probability of a febrile convulsion within a few minutes approaches unity—an observation true for nearly all mammals tested. Convulsions induced by radiofrequency radiation indicate a dangerously intense field because morbidity and death frequently follow.[7,8]

Work stoppage. A hungry animal can be trained to work steadily to obtain food. Introduction of an agent that renders the animal ill or anoretic, or otherwise disables it, stops work. Several studies have shown that 918-and 2450-MHz. microwave fields stop work by rats after five to 20 minutes of irradiation when whole-body energy-dose rates have respectively ranged from ~20 to ~5 mW/g.[9,10,11] The energy dose associated with these time-intensity values—when the animal is not subjected to the additional stress of corporal restraint—is approximately 9 J/g. The power densities of irradiation that result in the cited dose rates would range upward from 10 to 150 mW/cm.^{2} or more, depending on the efficiency of energy absorption. Unlike convulsions, death has not been observed at threshold doses for work stoppage during brief exposures (<30 min.). Indeed, tests of behavioral competency performed 24 hours after irradiation have revealed full recovery of an animal's ability to perform light work.[9,11]

Work perturbation. Closely related to measures of work stoppage are those of work perturbation, i.e., where the rate or efficiency of performance is altered, perhaps even facilitated, but is not disrupted. Recent studies of the squirrel monkey by de Lorge[12] not only exemplify the case of behavioral perturbation, but illustrate how animals larger than mice and rats have much higher tolerance for microwave fields of a given frequency and intensity. De Lorge's monkeys worked at a two-lever task that required adroitness in discrimination and timing to achieve rewards of small pellets of food. After the monkeys had been partially deprived of food until body mass was reduced by 10%, which insured strong motivation to perform the two-lever task, they were exposed to 2,450 MHz. fields that ranged in power density from 0 to 75 mW/cm.^{2} and were concentrated on the upper torso and head. Performance was not reliably affected until rectal temperatures were elevated by 1°C. or more. The irradiation required to produce a 1°C. change in temperature was near 50 mW/cm.^{2} for a 30-minute duration of exposure. Disruption of performance did not occur in the monkeys until power density was increased above 60 mW/cm.^{2} Even after exposures at 70 to 75 mW/cm.^{2}, which were strongly disruptive, the impairment of performance was only temporary. Dosimetric measurements were not made by de Lorge, but I estimate that the wholebody energy dose associated with the monkeys' thresholds of perturbation—slowed or increased rates or responding—ranges from 5 to 7 J/g.

Endurance. The work-stoppage and work-decrement experiments described above were all based on tasks, such as the pressing of a lever, that do not require sustained, strenuous effort. When forced expenditure of effort at a task is required over a long period of time, one measures endurance if an agent is introduced that interferes with performance of the task. In an elegant study by Hunt and his colleagues,[13] rats were required to swim almost continuously in an automated, water-filled alley immediately after being subjected during a 30-minute period to sham radiation, or to radiation by 2.45-GHz. energy that resulted in a dose rate of 6.3 or of 11 mW/g. Rats absorbing energy at the higher dose rate, which resulted in an energy dose near 20 J/g., were markedly impaired during the initial period of swimming, then recovered and swam about 600 meters at a normal rate before again showing impaired performance. When tested 24 hours after irradiation at the 11-mW/g. dose rate, the rats' swimming speeds were normal for about 1,200 meters before their performance worsened relative to controls. Some of the controls could swim a distance of 9 km. during a 24-hour period.

The rats that had been absorbing energy at the rate of 6.3 mW/g. for 30 minutes, when tested immediately after irradiation, swam as well as controls for about 1,200 meters, then performed poorly over the next 600 meters before again swimming at speeds that fell within control values. The dose of energy imparted to these rats, about 11 J/g., was associated with a modest degradation of endurance when the animals were tested immediately after exposure to 2,450-MHz. RF fields that could range in intensity from just above 35 mW/cm.^{2} to 65 mW/cm.^{2}

Perception of RF fields. The perceptibility of radiofrequency fields is the most thoroughly established datum in the behavioral literature on such radiations, but a datum that must be qualified. The qualification relates to modulation of the radiofrequency field. When a radiofrequency field is sharply pulsed so as to produce a burst of electromagnetic waves of short rise time and high peak intensity, most individuals on whom the burst, of waves is incident hear a popping or clicking sound. This effect was first systematically studied by Allan Frey,[14,15,16] and is now believed by most scientists who have studied it to result from thermoelastic expansion of tissues in the head. Sudden if extremely slight heating of tissues, because of their thermally-dependent change of density, is believed to launch a minuscule pressure wave detected (as are ordinary sound waves) at the cochlea.[17-20] The threshold of radiofrequency hearing per pulse of detected energy is the smallest consensually validated dose of microwave radiation that results in a biological effect, about 10 to 20 μJ/g., animals of smaller mass being more sensitive. These doses of energy are so small that, near threshold levels, the resulting increases in brain temperature per pulse average less than one-hundred-thousandth of a degree ($<10^{-5}$°C.).[19]

The threshold of detection of unmodulated or of softly (sinusoidally) modulated radiofrequency waves is much higher than that of pulsed waves. King and her colleagues[21] utilized the most sensitive assay known to experimental psychologists to determine sensory thresholds and found that the threshold dose rate lies near 600 μW/g. in rats subjected for 60 seconds to sinusoidally modulated 2,450-MHz. microwaves. The corresponding energy dose is near a maximal value of 35 mJ/g. The range of averaged power densities of incident 2,450-MHz. energy that would result in a dose rate of 600 μW/g. in mature rats is about 3.5 to 6.0 mW/cm.^{2} Since the radiofrequency hearing effect depends on an energy dose three orders of magnitude below the threshold of detectable warming, to which the rats of King *et al.* presumably were responding, it follows that the (1-second) time-averaged power density at which threshold responding occurs to a single audible pulse of radiofrequency waves is near 2 to 3 μW/cm.^{2}

Aversive behavior. When pulsed 1.2-GHz. microwaves of a character associated with radiofrequency hearing are continuously presented to rats that are given a choice—they can stay in the field or leave it for an area shielded from the radiation—they tend to remain in the shielded area.[22,23] One gathers that the continuously pulsed field, which averages about 200 μW/cm.^{2} in power density, is not too aversive, because rats given the choice will repeatedly "probe" and enter the radiated area even though they develop a general preference for the shielded site. At 200 μW/cm.^{2} a

1.2 GHz. field would result in dose rates between 30 and 80 μW/g.

A seeming paradox to the relative ease with which a rodent can detect a pulsed or nonpulsed microwave field of moderate intensity (~20 mW/cm.^{2}) lies in the extreme difficulty rats encounter in learning to escape from highly intense radiation, at least when the field is not pulse modulated and is not heralded or accompanied by salient sensory stimuli.[24] At power densities near lethal levels for a 4- to 8-min. exposure, i.e., in an unpulsed 918-MHz. field that results in a dose rate of 60 mW/g., rats simply do not quickly learn a simple locomotor response that would immediately attenuate or extinguish the field.[24] The datum of detectibility of fields of low to moderate intensity but failure of escape learning in a nearly lethal field, is really not a paradox but demonstrates that the continuous presence of a field and its sudden cessation have quite different psychological properties. Several minutes of irradiation at 10 to 25 mW/cm.^{2} or more can produce detectible warming.[25] However, sudden cessation of the intense radiofrequency field evades sensory witness, probably because of the large thermal time constant of the mammal's well-hydrated tissues. In effect, the field extinguishes, but the elevated temperature of tissues in which thermal nocireceptors are situated declines too slowly to provide a discernible thermal cue to reinforce an escape response. Because of the poor detectability of the source of an attenuating or rapidly extinguished radiofrequency field, it is not surprising that human beings who work near unshielded or imperfectly shielded radiofrequency heaters in industrial settings have received intense irradiation, have developed symptoms of malaise, but have failed to discriminate the cause of their symptoms.[40]

General comment on experimental studies. A general rule is evident with respect to findings of behavioral reactivity during or shortly after acute exposures to radiofrequency radiation: The effects at high power densities above 100 mW/cm.^{2} are pronounced, easily recognized by the informed observer (if not by the uninformed recipient), and obviously thermally dangerous. At lower levels of such radiation, behavioral evidence of damage decreases rapidly; dose rates an order of magnitude below the rat's LD-50, which in a standard environment is near 35 mW/g. for a 20-minute exposure,[8] do not generate gross behavioral signs of harmful effects. It is true that effects per se are seen at much lower doses and dose rates (e.g., the radiofrequency hearing phenomenon), but no behavioral data implicate hazards for the animal acutely subjected to fields at aver-

TABLE I. REPRESENTATIVE DATA ON PROMPT BEHAVIORAL RESPONSES OF MAMMALS TO IRRADIATION BY RADIOFREQUENCY ELECTROMAGNETIC ENERGY

Class of behavior	*Citation No.*	*Species (mass)*	*Frequency and mode of irradiation**	*Duration of exposure†*	*Average power density*	*Energy dose rate‡*	*Energy dose*	*Mode of irradiation*
Aversion (Unpulsed fields)	24	Rat (300 g.)	918-MHz. sine	10 min. total	*125-375 mW/cm.²*	60 mW/g.	**5x7 J/g.**	Multimode cavity
Convulsions	7	Mouse (30 g.)	2,450-MHz. Sine	300 s.	*70-325 mW/cm.²*	80 mW/g.	**24 J/g.**	Multimode cavity
	7, 8	Rat (400 g.)	2,450-MHz. sine	380 s.	*440-800 mW/cm.²*	65 mW/g.	**25 J/g.**	Multimode cavity
Endurance	13	Rat (250 g.)	2,450-MHz. sine	30 min.	*30-80 mW/cm.²*	6 mW/g.	**11 J/g.**	Multimode cavity
	13	Rat (250 g.)	2,450-MHz. sine	30 min.	*55-140 mW/cm.²*	11 mW/g.	**20 J/g.**	Multimode cavity
Work stoppage	10	Rat (200 g.)	918-MHz. CW	6 min. (Avg.)	*8 mW/cm.²*	8 mW/g.	**3 J/g.**	Plane wave near field
	11	Rat (435 g.)	600-MHz. CW	22 min. (Avg.)	**20 mW/cm.²**	*2 to 14 mW/g.*	*3 to 18 J/g.*	Plane wave far field
Work perturbation	12	Squirrel monkey (900 g.)	2,450-MHz. CW	15 min.	**50 mW/cm.²**	*7 mW/g.*	*6 J/g.*	Plane wave far field
Aversion (pulsed fields)	22	Rat (250 g.)	1,200-MHz. pulsed	27 min. (cumul.)	**200 mW/cm.²**	*100 μW/g.*	*10 μJ/g. per pulse*	Plane wave far field
Perception (unpulsed fields)	21	Rat (425 g.)	2,450-MHz. Sine	<60 s	*3-6 mW/cm.²*	600 μW/g.	**≤36 mJ/g.**	Multimode cavity

TABLE I. (Continued)

Class of behavior	*Citation No.*	*Species (mass)*	*Frequency and mode of irradiation**	*Duration of exposure†*	*Average power density*	*Energy dose rate‡*	*Energy dose*	*Mode of irradiation*
Perception (pulsed fields)	19	Human (head only)	2,450-MHz. pulsed	5 μs. (repeated)	(Not applicable since single pulses are the variables of interest)		16 μJ/g. per pulse	Plane wave near field
	20	Guinea pig (head only)	918-MHz. pulsed	10 μs. (repeated)			6 μJ/g. per pulse	Wave-guide

The quantities shown for intensities of the incident field (power density) and for absorbed energy (dose rate and dose) are based on direct measurement (bold type), on calculations based on direct measurement (regular type), or on estimates (in Italics) via the *Radiofrequency Radiation Dosimetry Handbook* (see Durney et al., *Radio Science 14:*1979). As is evident, unless animals in a plane-wave field of constant intensity are immobilized, quantities of absorbed energy are usually highly variable. Irradiation in a cavity or waveguide can result in a constant rate of energy absorption, even by freely moving animals; the associated range of power densities is an estimate of limits, the minimal and maximal quantities that, depending on an animals's orientation in a plane-wave field, would be required to produce a given dose rate. As a rule of thumb—for brief exposures during which loss of thermal energy by the irradiated animal is minimal—the mean body temperature will rise by ~0.25°C. for each J/g. of absorbed radiation.

*Sine = sinusoidal modulation, CW = continuous (unmodulated) waves, Pulsed = pulse-modulated waves

†Duration generally refers to minimal period of time to production of a given behavioral response

‡Whole-body average

Comment

Escape behavior *not* demonstrated during 5 2-min. exposures at 2-min. intervals.

Temperature, humidity, and velocity of air flow in the environment are critical as is the animal's core temperature at initiation of irradiation. Convulsion occurs at a rectal temperature near 43°C.

Immed. after irradiation endurance was moderately less than that of controls.

Immed. after irradiation endurance was markedly less; 24 hours later endurance was moderately less than controls'.

Rats were under bodily restraint to maintain constant exposure geometry.

Rats were free to move about in a field of highly varying coupling characteristics.

Monkeys worked while restrained in a chair; work stoppage was not observed but quality of performance was impaired.

Marked behavioral aversion was not observed; rats exhibited a preference (70%) for the shielded side of a shuttle box.

Values for duration and energy dose are upper limits since animals demonstrated detection of field during 60-s. presentations.

Normal human volunteers were subjected to fields under several conditions of pulse width and peaks of power density; 16 μJ/g. was lowest threshold observed. The guinea pigs were irradiated with their heads in a special waveguide.

aged power densities below 1 mW/cm.^{2} A summary of acute (prompt) effects is given in Table I.

EPIDEMIOLOGICAL STUDIES

Lying in an indeterminate grey area between verifiable and imaginary behavioral effects of radiofrequency radiation are those cited in epidemiological reports. While epidemiological studies do not yield "hard" data, they have generated findings that command worldwide interest. Illustrative of the interest-provoking content is a study recently performed by Abraham Lilienfeld and his colleagues on former American employees of the United States Embassy in Moscow.[26] This study confirmed many earlier Eastern European reports with respect to neurasthenic symptoms among individuals working in stressful environments.[27-32]

The symptoms of neurasthenia are relatively persistent and include irritability, headache, lethargy, insomnia, irascibleness, impotence, and loss of libido—or what Western psychiatrists currently label the chronic depressive reaction.[33] While the syndrome doubtlessly exists, the specific attribution of microwaves and other radiofrequency fields as causative agents[27] was not supported by the Lilienfeld findings or, indeed, by many more recent Eastern European reports cited above. There is, however, the problem of interpreting the epidemiologist's necessarily uncontrolled observations. In the first place, the quantitation of strength of ambient fields has often been little more than guesswork. The industrial and military environments in which the typical epidemiological study has been performed contain so many variables that isolation and quantitation of specific sources of biological variation are extremely difficult.

Lilienfeld's group found that the incidence of neurasthenic symptoms among employees of the American embassy in Moscow is not positively correlated—and, indeed, is slightly negatively correlated—with levels of radiation measured inside and outside the Embassy with—for epidemiological studies—uncharacteristically great precision; however, even this negative finding will be challenged. Granted that levels of irradiation ranged from immeasurably low at the embassy's ground floor to maxima between 3 and 18 μW/cm.^{2} near the top floor, the assumption that personnel remained effectively invariant with respect to vertical location in the building will be argued: Some upward and (especially) downward mobility has to be assumed—or did personnel billeted in the upper stories arrive at their posts without entering the embassy at the ground level? Another challenge will come from those who confuse the effects of ionizing with those of nonionizing radiations and argue for a "hit" theory, i.e., they will argue that just the *presence* of the field, however low or high its strength, triggers the neurasthenic reaction.

I do not subscribe to the hit theory for radiofrequency waves, and, for that matter, consider Lilienfeld's correlative analysis of field strength versus neurasthenic incidence as useful and valid as any reported in the epidemiological literature. What I stress is that some individuals with the will to believe that extremely weak radiofrequency fields induce neurasthenia—and other, much graver ills—will conjure arguments to support their beliefs. I also stress that I do not succumb to the fallacy of an argument *ad ignorantiam:* While I can argue on unimpeachable grounds that a good case for a microwave etiology for neurasthenia has not been made, I cannot argue that the evidence nullifies a possible connection.

The question of a role of microwave fields in the etiology of neurasthenia is amenable to experimental resolution with animal models. A key feature of the neurasthenic syndrome—sexual incompetence—could easily be tested in rats and, of course, rabbits. Edward Hunt and I have argued during the past year for studies in which chronically irradiated animals are tested for sexual competency. Our arguments have fallen on ears scientifically sympathetic but deaf to sponsorship. As one colleague put it, "If we start counting the frequency with which an irradiated rabbit mounts its mate and then report the numbers in the open literature, we're certain to incur the wrath of Senator Proxmire and secure the ignominy of the Golden Fleece award."

Imaginary Psychological Reactions

For many years American biologists who worked with radiofrequency radiations looked askance at Eastern European reports of neurasthenia among personnel occupationally exposed to microwave fields well below the U.S. guide number of 10 $mW/cm.^2$ It is now realized that the studies giving rise to Eastern European reports of positive findings and the singularly negative American studies had little in common. Our Eastern confreres performed many relatively long-term experimental studies of animals at low levels of irradiation; we typically performed acute studies at relatively much higher levels. In retrospect, one must admit more than a little Yankee arrogance and a failure of scientific perspective to assume that the negative American findings cast doubt on positive reports from the East.

The failure of many American scientists to realize that the essence of confirmation or rebuttal lies in systematic replication does not, of course, validate Eastern claims of subtle, microwave-induced neuropathies and behavioral disorders. These claims still await laboratory confirmation or rebuttal because so many of the earlier studies—in the United States as well as abroad—were based on dosimetrically unanchored experiments in which the accuracy of measurement of field strengths of incident radiations is also suspect. Yet both irony and poetic justice attend claims by American authors that microwaves at very low levels"...can blind you, alter your behavior, [induce cancer], and even kill you,"[34] and are responsible for a high incidence of sudden death from heart attacks in Finland.[35] Because of the implication that fields at power densities well below 1 μW/cm.^{2} are involved in this alleged morbidity and mortality, even the most accepting of Eastern European scientists would find this litany of Yankee horror stories incredible.

I shall turn now to specific examples of imaginary effects of microwave radiation. Examples are illustrative but hardly exhaustive because constraints on imagination are far less limiting than those on the time and space required for rebuttal.

Mongoloid offspring of airline pilots. Paul Brodeur, in his book, *The Zapping of America,*[34] recounted the travails of Dr. Irvin Emanuel, now director of the Child Development and Mental Retardation Center in Seattle, Wash. When highly informal observations indicated that Down's syndrome might be correlated with paternal status as airline pilot, Dr. Emanuel sought support for a formal study from the national office of the Airline Pilot's Association. This was not forthcoming. The determined Dr. Emanual next screened nearly 200 birth certificates of mongoloid children born in the Seattle area. Examination of the certificates revealed that no such child had been sired by an airline pilot. Dr. Emanuel did find that the average age of the mothers of the mongoloid children was advanced, which agrees with the well-established correlation between maternal age and incidence of mongolism. When interviewed subsequently by Mr. Brodeur, Dr. Emanuel gave a full account of the informal observations *and* of the subsequent study. Only the informal observations were reported by Mr. Brodeur, which prompted Dr. Emanuel to write in a letter sent to me that "What [Mr. Brodeur] did not do was include my description of our maternal age findings as I have recounted them to you. I regard this as an important omission which slants my conversation more in his direction than I am willing to see in the light of the information which I have."

Others have studied the incidence of mongolism among populations in which fathers have had protracted, occupationally or service-connected exposures to radiofrequency radiation. Except for one report based on a statistical artifact, no relation has been found between Down's syndrome and paternal exposure to radiofrequency radiation. The "mongoloid connection," then, is largely in Mr. Brodeur's imagination, as is his assumption that airline pilots are exposed to dangerous levels of microwave radiation. Perhaps the source of radiation is the cockpit cathode-ray tube, my second example.

Video-display terminals. A notable case of cataracts in two young editors with the *New York Times* was reported in 1977 and 1978 in a succession of newspaper stories. The blame was placed on cathode-ray tubes inside video-display terminals used by the editors. (One gathers that these unfortunate gentlemen saw Mr. Brodeur in his appearance on Tom Snyder's televised show *Tomorrow*, during which Mr. Brodeur informed Mr. Snyder and millions of viewers that the cathode-ray tube of the video camera's monitor might be emitting microwave radiation at dangerous levels.)

Other stories appeared in which birth defects and abortions were also blamed on microwaves radiated by video-display terminals. Finally, the management of the *Times* arranged for a series of surveys by engineers of radiations emitted by these terminals. The only measurable levels of nonionizing radiation emitted by these instruments were those of visible light. These surveys were independently confirmed by scientists and engineers of the National Institute for Occupational Safety and Health.[36]

Who is radiating whom? Measurement of radiofrequency fields generated by electronic devices is necessarily referred to background levels. By definition, an immeasurably small level of radiation is one near or below the level of background radiation. Mr. Brodeur is quite correct in assuming that video-display terminals and other thermionic devices generate microwaves, but he seems to be unaware that all matter in the universe above a temperature of absolute zero emits "black-body" (including microwave and infrared) radiation. Within limits, the quantity of microwave energy emitted by a body increases with increasing temperature, in keeping with Planck's law. Indeed, the operator of a video-display terminal with a higher average temperature than the device he is looking at radiates more microwave energy at the device than he gets from it!

Standards Versus Ambient Levels of Microwaves

One last figment of the microwave-inflamed imagination is a presumed association between standards of microwave radiation and their ambient levels. One of the more frequently discussed riddles of microwave radiation is the highly restrictive Eastern European limits on continuous exposure three to four orders of magnitude below the voluntary guide number in the United States of 10 mW/cm.[2] Closely linked to this riddle is the supposition that environmental levels of microwave irradiation are much higher in the United States than in, say, the Soviet Union.

Recent surveys of densely populated areas of the United States by the Environmental Protection Agency reveal that in all but a tiny proportion of areas, levels of radiofrequency radiation are below the most stringent Eastern European limit.[37] While survey data do not indicate whether levels of such radiation are significantly lower in Moscow, say, than in New York City, they do indicate that *de facto* observance of a stringent civil standard is and has been the rule in the United States.

In some areas the stringent level is exceeded. Tall buildings in the vicinity of television and FM broadcast antennas are sometimes the recipients of signals that exceed 10 μW/cm.^{2}, but one assumes with some warrant that these excesses are as likely in some areas of Moscow—especially near the roof of the U.S. Embassy—as in New York City. Whatever the case, it does not follow that a statutory limit is commensurate with ambient levels of radiofrequency radiation.

With respect to the current United States guide number, I share with most contemporary radiobiologists the conviction that continuous, ultralong-term exposure of a biological system to radiofrequency radiation at 10 mW/cm.^{2} could augur for problems, particularly for emanations of VHF television and commercial FM transmitters. The twin factors of resonant absorption and relatively high fluxes of radiation deliberately and of necessity aimed at human populations could lead to hazards if field strengths of TV and FM signals approached the 10 mW/cm.^{2} level. While the scientific jury is out on the potential for irreversible harmful effects at much lower power densities, I doubt on intuitive grounds that there is any justification for the most stringent Eastern European standard, the 1 μW/cm.^{2} limit of Czechoslovakia. By establishing such a standard, our confreres in Czechoslovakia have effectively outlawed the bearing of children! The emission of "natural" microwave energy from a mother's body—from, specificially, the amniotic fluid that surrounds the fetus—

results in an incident whole-body flux of microwaves that effectively exceeds the statutory limit.*

One should not overlook some important implications of black-body radiation for scientists and physicians. First, a counterargument might be offered that radioactive elements are part of the fabric of biology. We are born with such elements, and we constantly absorb decaying isotopes from the external environment. Would one then argue that additional exposure to x or gamma-rays is therefore permissible or desirable? While answering strongly in the negative, I note an absence of parallelism between ionizing and "vital" (which is to say, infrared and microwave) radiations. Decaying isotopes are present in all biological bodies, but are irrelevant to metabolism; one could live and indeed live better without them. The vital microwave and infrared radiations are part and parcel of the metabolic stuff of living matter and, indeed, of all matter in motion. They are not exotic to the human condition but are an inseparable part. The incorporation of an excessive quantity of microwave or infrared radiation is certainly not desirable, but any argument that danger attends an encounter with exogenous microwaves at levels commensurate with and well below those inherent in the body begs an imagined peril that I am at a loss to comprehend.

Much easier to comprehend is the damage that can arise from false convictions—from the psychologically inspired physiological stress that attends anticipation of insult, contributes to chronic anxiety, and results in organic upset and deterioration among susceptible individuals.[39] Indeed, I believe there is far greater danger in false prophecy than in the weak electromagnetic fields around which the gloomy prophets spin their auguries of peril.

EPILOGUE

I have not commented much on that larger and essentially untested boundary of ultralong-term exposure to radiofrequency radiations. The flux of incident radiofrequency energy near 1 μW/cm.^{2} should hold no fear for

*By international convention, the spectrum of radiofrequency (RF) electromagnetic energy extends in 12 bands from just above zero hertz (D.C. or 0 Hz.) to 3 tHz. (terahertz= 10^{12} Hz.). The microwaves occupy Bands 9, 10, and 11 (300 MHz. to 300 GHz.) and thus are overlapped by one octave of radiofrequency radiation, Band 12, which also overlaps the infrared spectrum. If the radiant emittance of the human body is integrated over all 12 bands of the radiofrequency spectrum, the power-density number increases to $\sim$5 μW/cm.^{2} Moreover, integration of the human body's radiant emittance over the entirety of the radiofrequency and infrared spectra yields minimal and maximal power densities, respectively, near 3 and 50 mW/cm.^{2}, which reflect extremes of whole-body metabolic activity of "standard" man. The basal metabolic activity of the human brain is so great that its cells emit electromagnetic energy at a rate well in excess of 30 mW/cm.^{2}

reasons already mentioned. But there is a grey line of uncertainty that becomes ever more uncertain as that flux approaches the current American guide number of 10 mW/cm.[2] Need is manifest to explore that grey line experimentally, to assess the consequences of continuous radiofrequency irradiation over the life span and over generations of mammalian species with short spans of life. The need hardly inheres in present-day environmental levels of radiofrequency waves for the great majority of persons because man as a microwave radiator is much more the giver than the receiver, but the future bids strongly for ever increasing levels, especially if microwave-mediated energy is sought from the sun through the aegis of the solar-powered satellite.[38] We can experiment now in preparation for the future, or we can wait and let the future experiment on us.

Summary

The first category of behavioral reaction to microwaves and other radiofrequency electromagnetic radiations involves responses confirmed in laboratory experiments from which a dose-response picture indicates absence of damaging effects of acute exposures (typically less than 60 minutes) at whole-body energy-dose rates below 3 mW/g. To result in this dose rate, the power density of incident radiation could be as low as 2 to 3 mW/cm.^{2} for a small animal but would be on the order of 15 to 20 mW/cm.^{2} for a human being. The second category treats of behavioral sequelae of indeterminate origin observed during epidemiological studies of industrial and military populations. Because of the general lack of quantitative information on intensity of ambient radiofrequency fields and because of myriad uncontrolled variables in the mundane environment, the extant epidemiological findings are at best hypotheses in need of experimental verification. The third category is that of imagined effects of radiofrequency radiations at power densities so low as to fall below the human body's rate of emitting microwave energy. Examples cited are the belief that video-display terminals emit significant quantities of microwave energy and the thesis that airline pilots have a higher than normal probability of fathering mongoloid children because of excessive exposure to microwaves. Because chronic anxiety can produce systemic disruption, propagators of imaginary hazards of microwave radiation probably generate more stress and disease in suggestible populations than the low-intensity fields to which all manner of ills are attributed.

Appendix I

ENERGY QUANTITIES AND CONCEPTS USED IN BIOLOGICAL STUDIES OF RADIOFREQUENCY ELECTROMAGNETIC RADIATION

Dosimetric units. In the System Internationale (S.I.) of quantities and units, the formal unit of all forms of energy—kinetic or potential, electrical or radiant, thermal or mechanical—is the joule (J). One joule is the equivalent of 10^7 ergs and of 0.239 "small" calories. Moderately active "Standard Man," for example, requires about 12,552 J of energy a day from ingested food to maintain his body mass of 70 kg., i.e., 1/0.239 = 4.184, which, multiplied by 3,000 calories = 12,552 J or ~ 12.5 kilojoules (kJ) per day.

When the joule is normalized to body mass in kilograms (joules per kilogram = J/kg.), these S.I. units express the energy dose, the amount of energy per unit of mass imparted to an absorbing body. A working unit of joules per gram (J/g.) is often used for convenience. Standard Man's daily nutritional dose in joules is ~179 J/kg. or ~0.18 J/g.

The watt (W) is the S.I. unit of the time-averaged rate at which energy is generated, transferred, transformed, absorbed, or dissipated. Accordingly, W is defined as number of joules per second (W= J/s.). To express the mass-normalized time rate of energy generation, transformation, etc., the appropriate S.I. unit is W/kg., which is widely used as the radiofrequency energy dose rate and is also known as the Specific Absorption Rate or SAR [working units are milliwatts per gram (mW/g.), and microwatts per gram (μW/g)]. For comparison, Standard Man metabolizes energy at a whole-body averaged rate of 1 mW/g. (sleeping), 2 mW/g. (light activity), 10 mW/g. (severe exercise), or 18 mW/g. (running up a flight of stairs).

The metabolic rate is not a dose rate, which is defined as the mass-normalized rate of incorporation of external energy; the numbers given for various levels of metabolic activity are cited solely to provide the reader with a frame of reference for appreciating rates at which radiofrequency energy is incorporated into a biological body. Energy-dose and energy-dose-rate numbers carry no necessary metabolic meaning, but simply express quantities of rates of *physical* heating, latent or kinetic, by absorbed electromagnetic energy. Heat is defined physically as energy in transit from a source to an absorbing body; heating is simply the rate at which any form of energy, microscopically speaking, is coupled to an ensemble of molecules. Heat is not to be confused with temperature, which is the average kinetic energy of a system of molecules. It is an anomaly of the English language that only one adjective, "thermal," is used to modify the different constructs of heat and temperature. This anomaly has been the source of much confusion because one investigator's claim of nonthermal effects of microwaves may be intended to mean an effect not based on a measurable change of temperature, while another investigator may mean *no* effect of temperature, and yet another investigator may unwittingly intend an effect not based on heating (i.e., not based on transfer and absorption of energy). The latter meaning is a physical contradiction in terms because an effect cannot be induced in a system by an external agent unless energy is imparted. The only valid meaning of nonthermal radiofrequency radiation (in the sense of a nonheating field) is that which is completely scattered (zero absorption) by the body on which it is incident. It is important to note that veridical thermal effects based on heating have several theoretical categories of causation, including increase of temperature (manifest heating), change of physical state (latent heating), and rate of increase of temperature, which is believed to be critical for the phenomenon of radiofrequency hearing.

The reader is cautioned at this juncture that the term "heating" is used in the physical, molecular sense of the word. I assume without fear of physical contradiction that absorption of a quantum of RF energy by an ensemble of molecules will increase their kinetic energy (kT). But an increase of kT from heating at the molecular level is no warrant that ensuing events at levels of greater structural complexity are a simple reflection of ΔkT. In that enormous and highly ordered aggregate of molecules known as the neuron, the RF field that invests it and its millions of interconnected counterparts may theoretically ignite macromolecular physiological events that are associated with but are not linearly attributable to ΔkT. By analogy, a coil of spring steel can be viewed at one level as a repository of potential energy as it is compressed, and as an exemplar of kinetic energy upon release, yet the myriad behaviors and consequences of such springs at the macromolecular level are only remotely attributable to micromolecular ΔkT. In recognition that J and W are constructs related to energy (and, as regards RF dosimetry, to electrical energy), there is no implication whatsoever that J/g. or W/g. as independent dosimetric variables possess that surplus of meaning that forces a "thermal" interpretation on any biological response to an absorbed RF radiation.

TABLE A-I. REPRESENTATIVE QUANTITIES, DEFINITIONS AND UNITS OF ELECTROMAGNETIC RADIATION RECOMMENDED BY IEC AND IOS

Quantity and definition	*SI unit*	
	Name	*Symbol*
Electromagnetic radiation		
The *radiant energy* Q_e (or W) is the energy emitted, transferred or received as radiation.	joule	J
The *radiant energy density* ω is the radiant energy in an element of volume divided by that element: $\omega = dQ_e/dV$.	joule per cubic meter	J/m.^{3}
The *radiant flux* or *radiant power* Φ_e is the time rate at which energy is emitted, transferred or received as radiation: $\Phi_e = P = dQ_e/dt$.	watt	W
The *radiant exitance* M_e at a point of a surface element is the radiant flux leaving an element of the surface divided by the area of that element: $\Phi M_e = \int_e dA$.	watts per square meter	W/m.^{2}
The *irradiance* or *energy flux density* ("power density") E_e at a point of a surface is the radiant flux incident on an element of the surface divided by the area of that element: $\Phi_e = \int E_e dA$.	watts per square meter	W/m.^{2}
The radiant exposure H_e is the time integral of the irradiance: $H_e = \int_e t$.	joule per square meter	J/m.^{2}

Reproduced by permission from Justesen, D.R.: Toward a prescriptive grammar for the radiobiology of nonionising radiations: Quantities, definitions, and units of absorbed electromagnetic energy. *J. Microwave Power 10:*343-56, 1975.

Densimetric units. Radiofrequency waves incident on a biological body are often characterized by one or more of three sets of S.I. units, volts per meter (V/m. = electric-field strength), amperes per meter (A/m. = magnetic-field strength), and, especially in the microwave spectrum, watts per meter squared (W/m.^{2}). While V/m. and A/m. relate to the strengths of two field components of an RF wave, the W/m.^{2} (which is referred to formally as irradiance or energy flux density and informally as power density) relates to the average or peak quantities of energy that flow each second of time through a measured area of space. Watts or milliwatts per centimeter squared (W/cm.^{2} or mW/cm.^{2}) are commonly used derivations and have the relation of 10 W/m.^{2} = 1 mW/cm.^{2} = 1,000 μW/cm.^{2}

Power density is the cross-product of the two components of field

TABLE A-II. PROPOSED QUANTITIES, DEFINITIONS, AND UNITS FOR DOSING OF BIOLOGICAL BODIES WITH NONIONIZING ELECTROMAGNETIC RADIATION

Quantity and definition	*SI unit*	
	Name	*Symbol*
Absorbed electromagnetic energy		
The *energy dosage* Q_{ab} is the energy imparted to a biological body from irradiation by electromagnetic energy.	joule	J
The *energy dosage-rate* $\dot{Q}_{ab}$ is the time rate at which energy is imparted to a biological body from irradiation by electromagnetic energy.	watt	W
The *energy dose* D_{ab} is the energy imparted to an element of mass of a biological body from irradiation by electromagnetic energy. $D_{ab} = Q_{ab} M^1$	joule per kilogram	J/kg.[1]
The *energy dose-rate* $\dot{D}_{ab}$ is the time rate at which energy is imparted to an element of mass of a biological body from irradiation by electromagnetic energy. $\dot{D}_{ab}=\mathrm{d}D_{ab}/\mathrm{d}t$	watt per kilogram	W/kg.[1]

Reproduced by permission from Justesen, D.R.: Toward a prescriptive grammar for the radiobiology of nonionising radiations: Quantities, definitions, and units of absorbed electromagnetic energy. *J. Microwave Power 10:*343, 56, 1975.

strength and, as an expression of propagating radiofrequency energy, is not a dosimetric measure. Because of the many electrical and anatomical variables that control the quantity of energy absorbed by a body in a field of a given power density (see Gandhi, p. 999, this issue), the power-density number is only a crude index of the dose rate.

Tables A-I and A-II summarize respectively formal S.I. quantities, units, and nomenclatures for radio densitometry, and related conventions, and formal S.I. units and quantities for radio dosimetry (nomenclatures have been proposed but have yet to be resolved by the S.I. arbiters).

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NEUROPHYSIOLOGIC EFFECTS OF RADIOFREQUENCY AND MICROWAVE RADIATION*

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Over the past five years awareness has been increasing among neurobiologists of ways in which information is processed in brain tissue.[1]

Three lines of recent evidence are sharply at variance with most of what we learned in medical school about information transaction in central nervous tissue. The first line of evidence indicates that cell-to-cell communication between brain cells probably involves only slow waves in much of these interactions. The second is that brain cells sense electric fields in their own environment and that these fields are far below those electric gradients associated with synaptic processes. Specifically, I shall address the apparent role of the oscillating electric fields in the fluid around cells as an element in transaction of information.

The third line of investigation is even more remote from classical biochemistry and physiology of brain tissue, in that it addresses the virtual certainty that at least some classes of information transaction at the surfaces of brain cells involve nonequilibrium processes. Under that impressive term is subsumed the simple concept that we no longer think of ions massively transferred from one side of a membrane to another in the initial steps of excitation, but rather that there are forms of resonant interaction between ions located at binding sites on membrane charge sites, surface macromolecules, and that they ''see'' one another at considerable atomic

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distances. Given these three lines of evidence that may help us understand some aspects of field interactions with brain tissue, what should we look for in central nervous interactions with an impressed electromagnetic field? First, we should seek a structural substrate in the anatomy of cerebral tissue. Second, we should search for physiological and biochemical effects, and, third, we should seek behavioral correlates.

Possible Anatomical Substrates for Field Interactions with Brain Tissue

In simple nervous systems, such as those that characterize the simplest animals like *Hydra,* there are no "interneurons." A sensory cell is connected directly to a motor cell. There is no opportunity for the plasticity of a changing response that might result from a continuing pattern of stimuli. A typical brain is really a great overgrowth of interneurons interposed between the sensing cell and the motor apparatus. In *Hydra,* for example, there are neuroepithelial cells at intervals in the epidermis. Typically, they connect directly to a muscular apparatus between the external epidermis and the endoderm. By contrast, the brain is constituted of an enormous number of interneuronal cells, and in all vertebrates, particularly in mammals, brain neurons differ from neurons in the rest of the nervous system in that the cortical neuron has a very small cell body and a huge series of branches that we call dendrites, extending out for a vast distance. Dendrites make contact with dendrites in a functional sense and "dendrites speak unto dendrites."[2] It is in this structural substrate that there appears to be at least one elemental aspect of a possible interaction with environmental fields.

The ontogeny of cortical development provides further evidence of the importance of dendrites in cortical tissue. In the human infant brain at birth, cell bodies are widely separated. There is very little dendritic growth. At four months, cell "packing density" is no higher, but dendrites start to grow out. By 15 months there has been a vast proliferation of dendrites, though still incomplete, and those from one neuron make contact with dendrites of other neurons. The older classical concept envisaged a "through" neuronal circuit with a nerve fiber terminal in contact with a cell body (or soma), then carrying a traffic of impulses, and ending in a synaptic terminal on another neuron. That concept is being replaced by one in which there are interactions through dendrites contacting dendrites of an adjacent neuron. In the retina, for example, the activated receptor transmits activity to bipolar cells and horizontal cells and on down to amacrine cells. No impulses occur until activity reaches some of the large amacrine cells and cells in the ganglionic layer that give rise to the optic fibers. Neurophysiologists now speak of a "silent retina," to exemplify that its essential initial transactions do not involve impulses, but only slow, wavelike activity. Similarly, there is slow, wavelike activity in the olfactory bulb. If we look at the way in which dendrites "speak unto dendrites," the synapses are often reciprocal, placed one alongside of each other, with activity passing in opposite directions through adjacent synaptic connections. Evidence of this type is exemplified by the finding that about 60% of cells in cerebral cortex have no long nerve fiber (or axon). They communicate through dendrite-to-dendrite contact. These cells are the majority of neurons in the cortex and are known as Golgi type II cells.

Possible Physiological Substrates of Electromagnetic Field Interactions with Cerebral Tissue

What are the physiological mechanisms on which the environmental field might impinge? As noted above, the electric process between dendrites is one of slow waves, not impulses. The integral of the slow wave activity between dendrites constitutes the electroencephalogram. This can be recorded in the fluid surrounding brain cells, as well as outside the skull.

With sophisticated microelectrode recording, it is possible to place an electrode inside the body of a cortical neuron. It was a surprising finding that in many neurons the baseline of the intracellular membrane potential is not steady. It oscillates in a wavelike fashion, due to waves produced in the dendrites. Only at intervals do we see the production of impulses. When the animal is asleep, the electroencephalogram is slow, as are the waves inside the cell. When the brain is awake, the electroencephalogram is fast, as are the waves inside the cell. One can carry out very complex mathematical analyses showing these relations. The electroencephalogram is produced by the leakage of these big waves inside dendrites into the fluid around the cell. The difference in size is about 200 to 1. The electroencephalogram recorded over the dimensions of the cell is a few microvolts. The neuronal wave inside the cell is of the order of 5 to 15 millivolts. Thus, the difference in amplitudes is about 200 to 1. Firing of the cell is a high order transform of these waves inside the cell. Firing of the cell to produce an impulse is always on the positive going peak of the intracellular wave, but often there are very large waves inside the cell and no impulse is produced.

Given this background, we may conclude that the cerebral neuron has a large dendritic apparatus; its transactional processes involve waves; it transmits waves to other cells; it leaks waves into its own environment.[3] Thus we come down to a critical question. Does the electroencephalogram in the fluid around the cell have an informational content? Do brain cells sense the electroencephalogram around them? Or, as many have said, is the electroencephalogram "the noise of the brain's motor"? If it is only the noise of the brain's motor, then the fields around the head entering the electroencephalogram's domain would be expected to be as ineffective as the electroencephalogram in changing the animal's behavior. If the electroencephalogram does have informational significance, can one induce subtle behavioral changes if one imposes environmental fields that look like the electroencephalogram?

I do not propose to discuss studies that have shown that the electroencephalogram is very finely correlated with behavior. By computer analysis, one can show that there are patterns in individuals that characterize them when they are lying or when they are emotionally disturbed.[4,5] These signatures for the individual are as unique to them as their fingerprints, and they share those signatures with a group of subjects. One can also develop group signatures for the same psychological correlates. However, I shall discuss the electroencephalogram as a phenomenon in tissue and consider how it might relate to fields in the environment impressed on the head.

Let us first consider the levels of typical environmental fields. If we sleep under an electric blanket, the field is of the order of 200 volts per meter. If we walk under a high voltage 60 cycle power line or a DC power line, the field is on the order of 10,000 volts per meter. A hair dryer against the head produces a magnetic field of about 30 gauss, or roughly 100 times the background field. A microwave oven may leak as much as 5 $mW/cm.^2$ at the door. This translates into an electric field of 130 volts per meter. A powerful handy-talkie will produce 130 volts per meter at the head. As Mr. Janes has pointed out, a high background of radiofrequency fields in suburbia is 1 to 4 $\mu W/cm.^2$, 2 to 4 V/m. I shall stress volts per meter as the parameter in the environment because this translates to tissue gradients in volts per centimeter, which gives a measure of potential ability to excite brain tissue.

Some tissue sensitivities to environmental electric fields are extremely high. Sharks and rays navigate and exhibit predation in fields of one hundred millionth of a volt per centimeter. Nevertheless, this sensitivity is not anomalous in terms of normal tissue thermal noise produced by molecular collisions, and appears to relate to properties of cell membrane surface electric fields. These fields limit the speed of ion movements along the membrane surface, and thus may diminish interfering effects from thermal agitation. Moreover, this electric field sensitivity of sharks and rays lies in an intensity "window." The upper limit of the window is about 100 times the threshold strength. Above this, the phenomenon disappears. It is limited in the frequency window DC to 10 Hz.[6]

Migrating birds cut diagonally across the horizontal component of the earth's magnetic field. It has been suggested that nodding of their heads has something to do with this sensitivity. It is of the same order as in sharks and rays, 10^{-7} V/cm. Circadian rhythms in birds, subjective time estimates in monkeys, and circadian rhythms in man appear similarly sensitive.[7,8] These are extremely weak gradients by comparison with the size of natural electric phenomena in nerve tissue. The membrane potential is 100,000 V/cm. A synaptic potential changes the membrane potential by 1,000 V/cm. The electroencephalogram is 0.1 V/cm., measured over the dimensions of a single cell. One would assume that this gradient is so small at 0.1 V/cm. that there was no way for it to modify directly the excitability of the cell through its effect on the membrane potential. It certainly could not unless there were certain amplifying mechanisms. I shall address some relevant physiological models.

Sharks and rays have tubular electroreceptors, the ampullae of Lorenzini, on their heads. These tubes have a high wall resistance. This rapidly attenuates responses at increasing frequencies of field oscillation. The mechanism is known to be used in orienting, navigating, and searching for prey.

Wever in Germany has done interesting experiments in human subjects in underground chambers. Shielded from weak environmental electric fields, the free-running 24-hour cycle has a period as long as 26.6 hours in some subjects. Imposition of a 10 Hz., 2.5 V/m. field, which produces about 10^{-7}/V/cm. in the tissue, caused the rhythm to change back toward 24 hours. Turning the field off again after eight days was then followed by cycles lasting 36.7 hours, as measured by sleep and wakefulness.

It may be argued that perhaps there were cues for man in those chambers. The experiment was therefore repeated with birds and, again, in the presence of the 10 Hz., 2.5 V/m. field, the bird's daily activity was locked around 24 hours. When, after 10 to 15 days, the field in the shielded chamber was turned off, the diurnal rhythm became substantially longer. The effect reversed when the field was restored. It is clear that the environmental field in the shielded chamber provided some essential stimulus for maintenance of normal circadian rhythms.

Experiments in our own laboratory have shown an influence of similar weak fields when they are imposed across the chamber in which a monkey is sitting. They affect its ability to estimate the passage of time in the absence of external cues. A 5.0 second estimate brings an apple juice reward. The estimate of 5.0 seconds is reduced by about 0.5 seconds by a 7.0 Hz. field of 56 V/m. At 10 Hz. the effect is less. A 10 V/m. field has less effect and a 1.0 V/m. field produces virtually nothing. The Illinois Institute of Technology Research Institute has measured total current induced by a 10 V/m., 7 Hz. field in a phantom monkey head at 0.9 nA. From this we conclude that the tissue gradient is of the order of 10^{-7} V/cm.

We have done much work with 147 MHz. VHF radio fields and with 450 MHz. microwave fields. We have an anechoic microwave chamber set up for 450 MHz. First, I shall discuss some electroencephalographic experiments with metal electrodes implanted in the brains of cats. This is not now considered to be good engineering practice, but from spectral analysis of electroencephalographic trainings we conclude that the presence of the metal wires in the brain did not significantly contribute an artifact to the records. From the spectral analysis it is clear that the radio signal at the electrodes was less than 0.1 μV, or 200 times less than the electroencephalographic signal.

In animals and man EEG records tracings from deep brain structures normally exhibit spontaneous rhythm patterns. These appear as bursts of waves in different brain structures that last for two to three seconds. Animals can be trained to make these bursts by reward or punishment. For example, if one presents a flash of light, the animal must make that response within two seconds or be "punished." In this punishment the eyes are involuntarily deviated to the opposite side by stimulation of the brain itself. This is unpleasant but not painful. After training for two or three days, presentation of the flash of light is followed by these bursts of waves in about 80% of the tests.[9]

After training in this way, punishment may be omitted. Without punishment, in what are called "extinction trials," performance drops very rapidly in a day or so to the level before training. On the other hand, if the animal is trained in the presence of a radiofrequency signal modulated at the frequency of the particular brain signature, the number of correct responses goes much higher, to over 90%. In the ensuing extinction trials, where no punishment is given, the animal keeps on performing at a level significantly above chance for almost two months in the absence of any punishment. Thus, the presence of the field appears to delay the "forgetting" of the learned habit as well as enhancing correct responding in training trials.

Incident energy of these fields was about 0.8 mW/cm.[2] Tissue dosimetry indicates that the field included an electroencephalographic level gradient in brain tissue, about 0.1 V/cm. No significant heating of tissue was involved.

In the context of these experiments, it should be mentioned that there is a medical therapeutic device, known as the LIDA, developed in the Soviet Union and patented in this country. It is designed for the treatment of psychoneurotic illness and emotional disorders. It emits pulsed radio signals up to one tenth of a second long at rates up to two per second, with a maximum generator output of 40 to 80 watts. The instrument can also generate pulsed light, sound, and heat, and the four stimulus modalities can be delivered separately or in any desired combination. Reports of clinical tests in the U.S.S.R. in juveniles and adults suffering from emotional disorders are said to have been favorable.

Role of Cell Membrane Surfaces in Detection of Weak Electromagnetic Fields

How does the brain sense these fields? The process appears to relate to effects at the surface of the cell where there is a highly organized glycoprotein glue-like material, specialized in places where there are synapses at the surface of the cell and interposed also between the surface of the neuron and the neuroglia. This concept has been developed in detail in the Singer-Nicolson fluid mosaic model.[10] In this model, attention is directed to lipid and protein molecules inserted into the lipid bilayer of the plasma membrane or classic cell membrane. Many of these intramembranous particles have stranded external protrusions negatively charged at their terminations, which are sialic acid molecules. These charged terminals constitute a polyanionic sheet. Thus, the surface of virtually all normal cells is a sheet of negatively charged glycoprotein material that attracts cations, specifically, calcium and hydrogen ions that compete for most of these binding sites. Those two ions are the subject of an elaborate model of excitability and transductive coupling developed by Bass and Moore[11] more than 10 years ago. This interaction of hydrogen and calcium ions on cell-surface glycoprotein strands suggests that this is the site of the first and most sensitive transductive couplings in brain tissue.

The concentration of calcium is high on the outside of the cell (about 2 mM), and low inside in general cytoplasm (10^{-7}M). Calcium ions have been implicated in essentially every step of the transductive coupling of neurotransmitter substances in effects of every step of immunologic reactions and every step of the coupling of hormonal binding at membrane surfaces to cellular mechanisms. Calcium ions appear to hold the key to an understanding of every aspect of cell-surface transduction.

SENSITIVITY OF CALCIUM BINDING IN BRAIN TISSUE TO IMPRESSED ELECTRICAL FIELDS

Field interactions with brain tissue have been assessed by effects on calcium ion fluxes. In our laboratory the effects of electric fields on brain chemistry was first studied in the awake cat. With this method one can stimulate the cortex directly with very large electrodes that produce a relatively uniform electric gradient through the whole cerebral substance. This field can resemble the electroencephalogram in frequency. At the same time, a central well formed by a plastic cylinder over the exposed cerebral cortex can be used to place radioactive tracer substances in contact with the brain. After a period of equilibration, we can examine their efflux back into the well.[12] An electroencephalogram-level gradient imposed on that cerebral hemisphere causes a 20% increase in calcium efflux and a similar increase in the efflux increase in the efflux of the amino acid neurotransmitter gammaaminobutyric acid.

We have estimated the level of that gradient as only 1.0 μV across a synaptic terminal 0.5 μm. in diameter. This field would be less than one ten thousandth of the 50 mV membrane potential of the synaptic terminal. An amplification mechanism would appear necessary for such a weak extracellular field to influence transmitter release from within the synaptic terminal. This led us to examine the effects of weak imposed fields rather than direct stimulation. We tested the effects of sinusoidal extra low frequency (ELF) fields on the isolated chick cerebral hemisphere at a

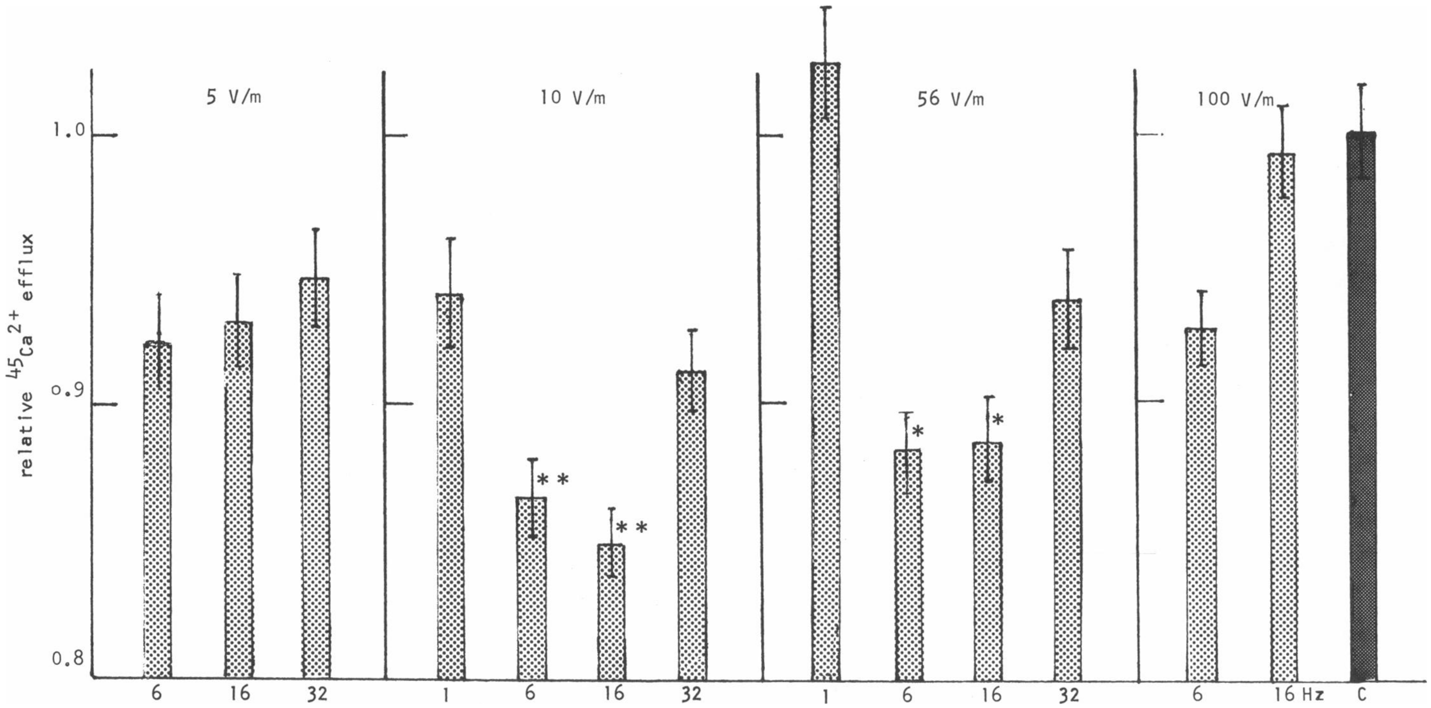

Fig. 1. Effects of extremely low frequency fields on $^{45}Ca^{2+}$ efflux from chick forebrain. The relative $^{45}Ca^{2+}$ effluxes, given ± SEM, are referred to the mean value of control condition (C). *, $p<0.01$ that the mean is the same as that of the control. Reproduced by permission from Bawin, S. M. and Adey, W. R.: Sensitivity of calcium binding in cerebral tissue to weak environmental electric fields oscillating at low frequency. *Proc. Nat. Acad. Sci. U.S.A.* *73*:1999-2003, 1976.

number of frequencies from 1 to 32 Hz. and at a number of intensities from 5 to 100 V/m. (Figure 1). At 5 V/m., as compared with the means of control values in all experiments, occurred a nonsignificant reduction in calcium efflux. At 10 V/m. there was a significant reduction in calcium efflux for fields at 6 and 16 Hz. At 56 V/m. a similar reduction was significant at 6 and 16 Hz.[13]

In summary, these studies have disclosed a frequency window between 6 and 16 Hz. and an amplitude window, with significant effects for fields of 10 and 56 V/m., but not for 5 or 100 V/m. This is very suggestive of some form of quantum amplification. An amplifying process is involved. The findings are not consistent with such ionic equilibrium phenomena as those described in the Hodgkin-Huxley model of excitation. Moreover, electric gradients in these cerebral hemispheres were of the order of 10^{-7} V/m., based on measurements of total current induced by similar fields in tissue phantoms.

We repeated these experiments with radiofrequency signals using sinusoidal amplitude modulation from 0.5 to 35 Hz. These radiofrequency fields coupled much more strongly into the tissue. Thus, a 147 MHz., 0.8 mW/cm.^{2} field produces about 50 mV/cm. electric gradient in tissue, or about the same gradient as the EEG. Chick cerebral hemispheres exposed to this field showed a "tuning curve" in relation to modulation frequencies between 0.5 and 35 Hz., but were unresponsive to the unmodulated carrier wave (Figure 2). When modulated between 6 and 20 Hz., there was a highly significant increase in the calcium efflux, but not at higher or lower modulation frequencies. Thus, the modulation frequency becomes a very significant aspect of these interactions.[14]

Next, we searched for and found an amplitude window. The effects were only present when the incident energy of a 450 MHz. field, amplitude modulated at 16 Hz., was between 0.1 and 1.0 mW/cm.^{2} (Figure 3).[15] Using Bassen's tripole probe described at this conference by Mr. David E. Janes, we measured electroencephalogram-level gradients, 50 to 100 mV/cm. Higher and lower intensities were without effect. This amplitude window for radiofrequency fields was first noted by Blackman and his colleagues, who have also confirmed the modulation frequency sensitivity.[16]

Questions have been raised concerning the relevance of these findings in isolated chick cerebral hemispheres to possible sensitivity of intact mammalian brain tissue. In continuing studies we have exposed awake cats

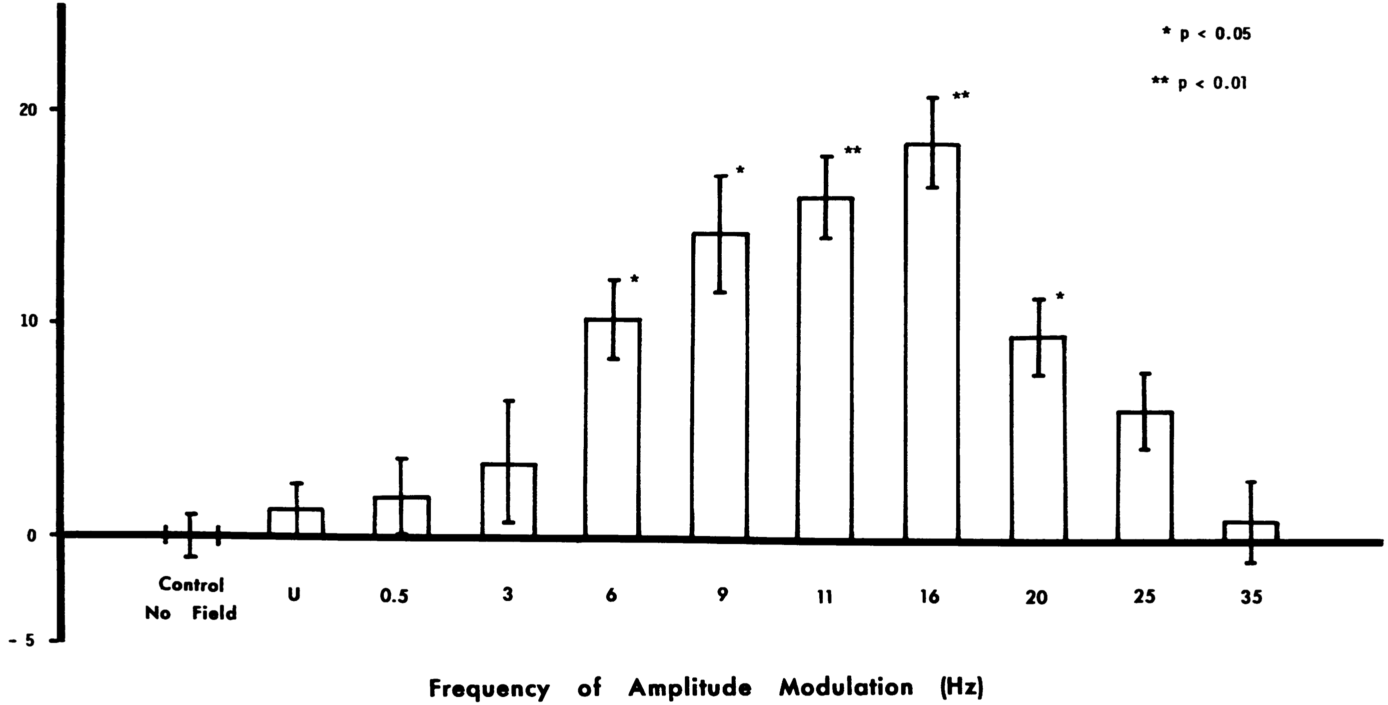

Fig. 2. Effects of amplitude-modulated 147 MHz. fields on the $^{45}Ca^{2+}$ efflux from the isolated forebrain of the neonatal chick. The results, given ± SEM, are expressed as percentage of increase of the calcium efflux, by comparison with control condition, in the absence of fields. *,$p < 0.05$; **,$p < 0.01$. Reproduced by permission from Bawin, S. M., Kazcmarek, L. K., and Adey, W. R.: Effects of modulated VHF fields on the central nervous system. *Ann. N.Y. Acad. Sci.* *247:*74-81, 1975.

under local anesthesia to a 450 MHz. 0.375 mW/cm.^{2} field, amplitude modulated at 16 Hz. In eight of the 12 experiments there was a sharp rise in $^{45}Ca^{2+}$ efflux, with a response curve identical to that obtained by direct electrical stimulation of brain tissue at the same intensity.

Chemical and Physical Models of Interactive Processes

These phenomena appear to belong to a class of events called "cooperative processes," and are characterized by weak triggers at one point in a system producing a major effect at another point. That major effect may occur in immunological reactions, where antibodies on the surface of the cell are bridged back to the surface of the cell with lysis of the membrane. In that example the bridging occurs along elements of complement protein that enclose calcium and magnesium ions. In cooperative processes the system has already spent energy in preparing for this type of event. It is true also for endocrinological reactions, where the arrival of a hormone molecule at the surface of a cell produces a ripple effect that may involve large segments of the cell membrane. For the red cell, ripple effects of this kind can be produced by a very few hormone-mediating molecules, such as prostaglandin. Schwarz[17] has pointed out that energy levels of charge sites on a biopolymer sheet may become identical over considerable distances for periods in the millisecond range. In this condition of identical energy levels, adjacent charge sites are described as coherent. On the cell surface they are sustained in this condition by "pumping" to that energy level from within the cell. We may suggest that the membrane surface would be a functional patchwork of coherent zones separated by a "sea" of incoherent charge states. Calcium ions bound at charge sites within a coherent zone may be released or modified in their binding by very weak triggers from outside the coherent zone. A cooperative process may be initiated which spreads widely across adjacent coherent zones, a process millions of times stronger than the initial triggering event.

Emergent Concerns on Central Nervous Sensitivities to Nonionizing Radiofrequency Radiation.

What concerns should emerge from these studies of central nervous sensitivities to nonionizing radiofrequency radiation? First, that their cooperative character, as revealed by the windows in power and frequency, appears to set certain bounds on the optimal field characteristics for

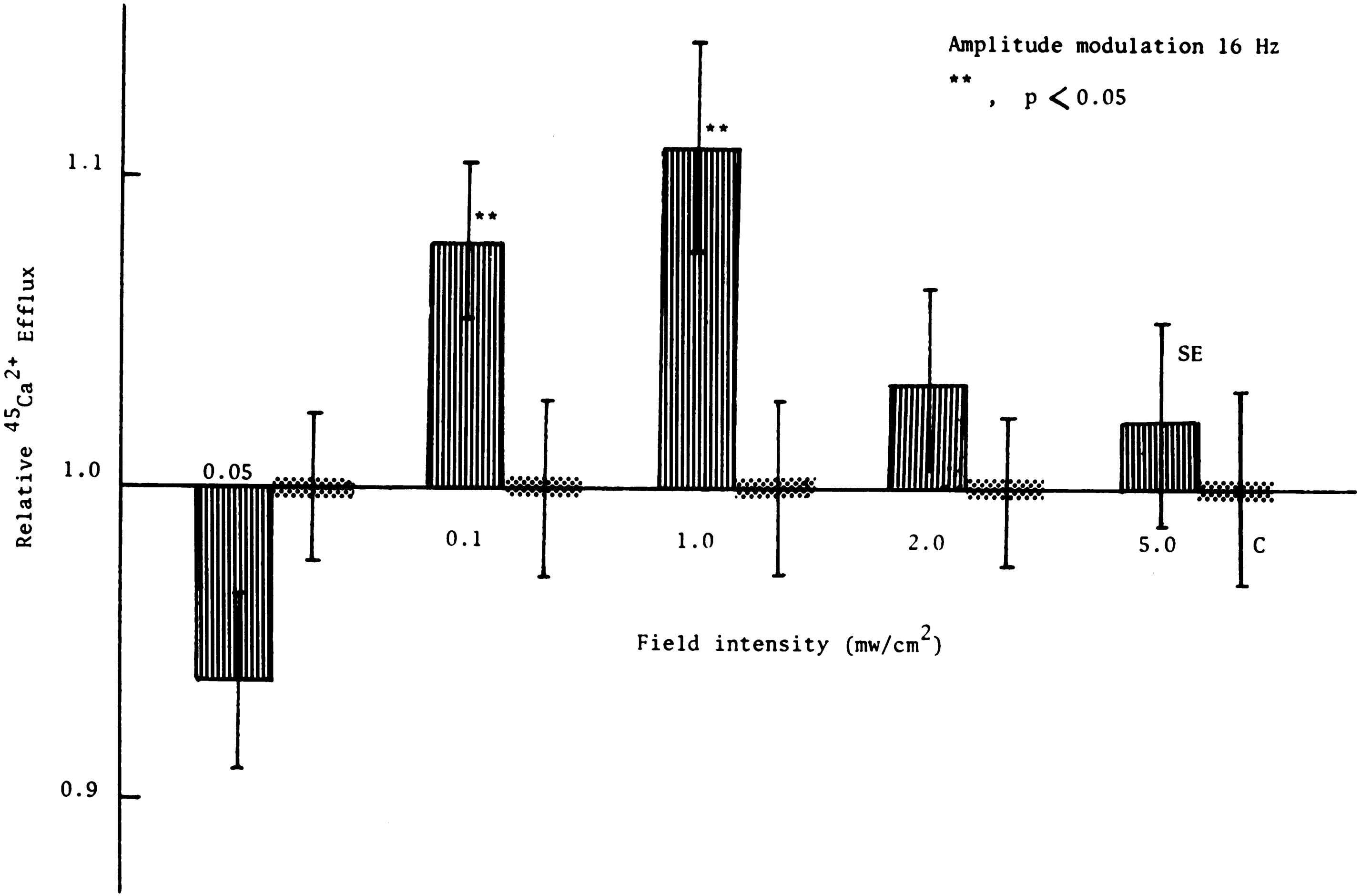

Fig. 3. Effects of changing intensity of 450 MHz. field amplitude modulated at 16 Hz. on efflux of $^{45}Ca^{2+}$ from chick cerebral hemispheres. Cross-hatched bars show levels of efflux from control specimens tested simultaneously in same series of exposures. Variance shows as SEMs. Reproduced by permission from Bawin, S. M., Sheppard, A. R., and Adey, W. R.: Possible mechanisms of weak electromagnetic field coupling in brain tissue. *Bioelectrochem. Bioenerg.* 5:67-76, 1978.

physiological interaction with the brain. Fortunately, communication and power distribution systems have not generally utilized oscillating generators in this range between 1 and 30 Hz., either as low frequency fields or as an amplitude modulation on a radiofrequency or microwave carrier. Some notable exceptions are now appearing and will merit close scrutiny and further research. In any event, groundwork has been laid that strongly emphasizes the potential impact of these specific signals at very low tissue levels, far below levels associated with a nominal thermal threshold around 0.1 C. Future research may indicate that long-term human exposure to signals with these particular low-frequency characteristics should be avoided or carefully controlled.

Our second concern should be to evaluate possible therapeutic applications that may be attributed to these very same modulation characteristics by direct enhancement or modification of intrinsic electrical rhythms that characterize the particular regions of cerebral cortex and vitally important deep brain nuclei. Their correlations with a variety of biological rhythms and behavioral states have become much clearer. Our ability to manipulate them for medical benefit has received little attention and the option is mentioned here in the context that nonionizing electromagnetic fields are not without considerable prospect in the pursuit of human health and relief of suffering from disordered brain funciton.

I suggest that our third concern is much broader. Faced with the overwhelming complexity of the brain as a tissue and as the organ of the mind, physical scientists and medical researchers alike have all too often retreated shamelessly into the classicisms and the argots of their respective trades. Too many physicists and engineers cling desperately to thermal models as the alpha and omega of bioeffects from nonionizing radiofrequency fields, shunning the exquisite beauty of long-range molecular interactions and resonant processes in biological macromolecules. In like fashion, medical physiologists, challenged by phenomena that I have discussed here, have turned away and fixed their eyes with a glassy stare on the comparative crudity of ionic equilibria as the be-all and end-all of excitatory processes as described in the massive ionic exchanges of Hodgkin-Huxley models.

True science can never be a popularity contest. The time has surely come when we should place these scholasticisms of another age in a proper context, counting ourselves thrice blessed at the prospect that through the use of nonionizing radiofrequency radiation as a research tool, the intrinsic organization of brain tissue, the subtleties of neuroendocrine phenomena, and the broad sweep of immunologic interactions may at last be understood in terms of transductive coupling at the molecular level.

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HEMATOLOGIC AND IMMUNOLOGIC EFFECTS OF NONIONIZING ELECTROMAGNETIC RADIATION*

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OVER the past several years much interest has been generated by reports of effects of nonionizing electromagnetic radiation (NEMR) on animal hematologic and immunologic systems. For the most part, these studies have been motivated by concern for the possible adverse health effects of NEMR for humans. Studies in which animals have been exposed at different frequencies and power intensities have shown inconsistent changes in elements of both systems. In some instances a thermal burden to the exposed animal has been credited with the observed changes, while in others a nonthermal or direct interaction of NEMR with the blood and blood-forming systems has been suggested to explain the observed effects. Traditionally, experiments performed in the Soviet Union and Eastern European countries have espoused the latter theory, an interpretation rooted in the approach that these investigators take in evaluating NEMR biological effects.

Historically, Soviet bloc-countries have centered their research efforts on the effects of long-term exposure of animals and humans to low intensity fields. Consequently, many early reports on direct NEMR effects come from these countries. On the other hand, research in the West has, until more recently, been concerned with the potentially deleterious effects of NEMR fields of sufficient intensity to cause localized or generalized heat. In these studies, biological changes have been attributed to thermal stress. In any case, final interpretation of NEMR-induced changes requires consideration of many important factors that affect interaction of the NEMR field with the biological entity. Such variables as body shape,

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mass, radiation frequency, duration of exposure, field intensity, specific absorption rate, energy distribution, orientation of body in the field, ambient environmental conditions, area of the body exposed, and field modulation may all influence final results.

This paper reviews the effects of NEMR on the hematologic and immunologic systems of humans and laboratory animals. Much of the Soviet literature is omitted, either because of lack of reported experimental detail or unavailability of English translations. For convenience, the review is divided into two general topics: clinical and epidemiological human studies and animal studies. The animal studies are divided into a discussion of hematologic and immunologic effects. The latter topic is subdivided into studies in which cellular components of the immune system have been exposed *in vitro* and studies dealing with whole body or *in vivo* exposures, including NEMR-induced hyperthermia.

Human Studies

Only a few clinical or epidemiological studies report the effects of NEMR on the hematological system of humans. Published reports on humans exposed to NEMR generally lack information regarding exposure history, and adequate control groups are often lacking or are nonrepresentative. Baranski and Czerski[1] discuss these and other problems inherent in such studies in their book.

Most clinical and epidemiological studies of NEMR come from the Soviet Union. Lysina[2] reported no significant difference in the circulating erythrocyte counts of 100 workers exposed to superhigh frequency (SHF) fields but gave no information about frequency, intensity, or duration of the exposure. He observed slight increases in reticulocyte counts in exposed personnel but no change in leukocyte counts. In another Soviet report, Sokolov et al.[3] examined 131 persons suffering various forms of radiowave sickness induced by exposure to SHF fields. They had received exposure to significant levels (several $mW/cm.^2$) in past years, but specifics about the exposure conditions, frequency, intensity, duration, etc. are not given. Sokolov et al.[3] reported a significant decrease in circulating thrombocytes and leukocytes due to neutropenia and relative lymphocytosis, a tendency toward reticulocytosis, increased bone-marrow erythronormoblasts, and an increase in the number of circulating cells undergoing mitosis. These hematologic effects, however, were reported as reversible, and cessation of exposure led to normal hemopoiesis in most patients. These investigators[3] found no reason to believe that hypoplastic changes or leukemia follow exposure to SHF fields used in this study.

Few clinical or epidemiological studies in the United States have dealt with the possible health effects of NEMR. Daily[4] observed 45 men exposed to radar and high-frequency radiowaves for two months to nine years but gave no frequency or intensity levels. Periodic physical and blood examinations for 12 months revealed values within the normal range. Daily[4] reported "...no clinical evidence of damage to these personnel." Barron et al.[5] performed comprehensive physical examinations on radar personnel employed by an aircraft company. Two hundred twenty-six subjects with radar contact varying from occasional beam exposure to four hours a day and up to 13 years exposure were observed, although the frequency and intensity of the fields to which these individuals were exposed are not given. Barron et al.[5] mention that the radar bands most commonly associated with airborne equipment are the "S" and "X" bands near 2,900 MHz. and 9,000 MHz. respectively. Radar personnel were grouped by years of exposure and compared to controls of similar age. A significant decrease of polymorphonuclear cells was found in 25% of the radar personnel as compared to 12% in the control group. A marked increase in monocytes (above 6%) and eosinophiles (more than 4%) was detected in radar personnel, but the significance of these changes was not evaluated by these investigators.[5] Re-examination of 100 subjects after six to nine months of incidental contact with both "S" and "X" band radar revealed changes in erythrocyte counts, leukocyte counts, and relative numbers of polymorphonuclear cells. Barron et al.[5] found this "...paradoxical and difficult to interpret." In a later report, however, Barron and Baraff[6] stated that the changes were due to a variation in a laboratory technician's interpretation.

More recently, Lilienfeld et al.[7] evaluated the health of foreign service personnel stationed at the United States embassy in Moscow between 1953 and 1976. During and subsequent to this period of time, the American Embassy was irradiated with NEMR by the Soviets and exposure levels as high as 15 $\mu W/cm.^2$ were recorded from June 1975 to February 1976. In this study the health of employees stationed in Moscow was compared with those stationed in other Eastern European posts during the same period. No differences between these groups in mortality or various morbidity measures were found. The authors concluded that "no convincing evidence was discovered that would directly implicate the exposure to microwave radiation experienced by the employees at the Moscow embassy in the causation of any adverse health effects as of the time of this analysis.'' The authors noted several limitations in this study which influenced the probability of detecting statistically significant excess risks, problems in identification of the study population and classification of exposure status, incomplete response to health history questionnaires, and lack of adequate numbers.

Obviously, better defined clinical studies are needed to assess the human health effects of exposure to NEMR, perhaps by monitoring those occupationally exposed to NEMR.

Animal Studies

Hematology. Paucity of clinical and epidemiologic information on the health effects of NEMR has led to studies of the hematologic and immunologic systems of laboratory animals. Many early investigations of NEMR effects on the blood-forming system of laboratory animals employed field intensities of 10 mW/cm.^{2} and higher. For example, Diechmann et al.[8] reported significant leukocytosis, lymphocytosis, and neutrophilia in rats following seven hours of exposure to 24,000-MHz. pulse-modulated microwaves at 20 mW/cm.^{2} One week following exposure, peripheral blood values returned to normal. Rats exposed for three hours at 10 mW/cm.^{2} had the same changes, which returned to normal after two days. Increases in circulating erythrocytes, hemoglobin concentration, and hematocrit were observed in two strains of rats (Osborne-Mendel and CFN) exposed to 24,000 MHz. at 10 or 20 mW/cm.^{2}, but Fischer rats exposed under the same conditions had reduced circulating erythrocytes, hematocrit, and hemoglobin concentrations. No explanation for this discrepancy is given by the authors. In another experiment, Diechmann et. al.[9] exposed two dogs to 24,000-MHz. pulse-modulated (pulsed) fields at 24 mW/cm.^{2} One dog was exposed for 20 months, 6.7 hours per day, five days a week, while the second dog was exposed 16.5 hours per day four days a week. No significant changes were observed in blood volume, hematocrit, hemoglobin, erythrocytes, total and differential leukocytes, blood cholesterol, or protein-bound iodine. The only symptom attributed to the exposure was a slight loss in body weight. Two control dogs were employed in this study, but it was not indicated whether these dogs were sham or cage controls.

Kitsovskaya[10] exposed rats to 3,000-MHz. at 10, 40, or 100 mW/cm.^{2}

for various periods of time. No changes were found in rats exposed at 10 mW/cm.^{2} but at 40 and 100 mW/cm.^{2} circulating blood erythrocytes, leukocytes, and lymphocytes fell, and granulocytes increased in number. In contrast to the findings of Diechmann et al.,[8] these hematologic changes did not return to normal for months after cessation of exposures.

The apparent discrepancy between the results of Diechmann et al.[8] and Kitsovskaya[10] may be partially explained by the work of Michaelson et al.[11] These investigators reported that the hematopoietic effects of 2,800- and 1,280 MHz. pulsed fields depend upon the frequency, intensity, and duration of exposure. For example, dogs exposed to 2,800 MHz. had a marked decrease in circulating lymphocytes and eosinophils after six hours at 100 mW/cm.^{2} This exposure resulted in a mean rectal temperature increase of 1° C. Neutrophils remained slightly increased after 24 hours, while eosinophils and lymphocyte values returned to normal levels. After a two-hour exposure to 165 mW/cm.^{2} at 2,800 MHz., there was a slight leukopenia, neutropenia, and definite hemoconcentration. These changes were accompanied by a 1.7° C. rise in rectal temperature. Eosinopenia was still evident 24 hours after this exposure. General leukocytic changes were more apparent following exposure of dogs to 1,280 MHz. pulsed fields or to 200 MHz. continuous wave (CW) radiation. After exposure to 1,280 MHz. for six hours at 100 mW/cm.^{2}, dogs developed a leukocytosis and neutrophilia. After 24 hours the neutrophil level was still above pre-exposure levels. Both lymphocyte and eosinophil values were slightly depressed following exposure, but at 24 hours they were slightly higher than initial values. A six-hour exposure to 200 MHz. (CW) at 165 mW/cm.^{2} caused a marked increase in neutrophils and a slight decrease in lymphocytes. After 24 hours this trend was more evident. Michaelson et al.[11] concluded that the results indicated a stress response by the exposed animals brought about by stimulation of the hypothalmic or adrenal axis by the thermal influence of NEMR or both.

Spalding et al.[12] exposed mice to 800 MHz. fields at an average incident power density of 43 mW/cm.^{2} for two hours daily, five days a week for 35 weeks. These investigators found no changes in blood erythrocytes, leukocytes, hematocrit, or hemoglobin concentration, nor did the mean life span of control compared to exposed mice significantly differ. These investigators detected no changes in the peripheral blood picture of exposed mice, although a thermal burden was placed on these animals. Four mice died from thermal effects on the 33rd and 34th NEMR exposures.

In another long-term high incident power level study, Prausnitz and Susskind[13] exposed mice daily for 59 weeks to 9,270 MHz. pulsed microwaves at an average incident power density of 100 mW/cm.^{2} Mice were exposed for 4.5 minutes, after which an average body temperature rise of 3.5° C. was recorded. This regimen was calculated as one half the LD_{50} because nine minutes of exposure at this power density killed half of the mice. The longevity of the mice did not appear to be affected by this exposure according to these authors, but two pathological effects observed in this study were testicular degeneration and neoplasms of the white cells. One would expect testicular changes from the thermal load to the mice. Neoplasia was either monocytic or lymphatic leucosis or a lymphatic or myeloid leukemia. The authors make no attempt to explain this finding.

Effects at levels below 10 mW/cm.^{2} have also been reported. For example, Baranski[14,15] exposed guinea pigs and rabbits to continuous or pulse-modulated 3,000 MHz. microwaves at an average power density of 3.5 mW/cm.^{2} for three months, three hours daily. At this power level the body temperature of the animals was not elevated. Increases in absolute lymphocyte counts in peripheral blood, abnormalities in nuclear structure, and mitosis in the erythroblastic cell series in the bone marrow and in lymphoid cells in lymph nodes and spleen were observed. No changes were observed in peripheral blood granulocytes. Shifts in peripheral blood cells correlated with changes in the cellularity of the spleen and lymph nodes. An increase in the mitotic index and in the percentage of cells incorporating ^{3}H-thymidine was observed. Baranski[15] suggested that the specific effect causing the observed quantitative and qualitative differences in the white blood cell system were not a thermal effect of microwave radiation because experimental conditions excluded such a possibility. He stated that the mechanism should be investigated at the cellular level.

Djordjevic and Kolak[16] exposed rats to 2,400 MHz. (CW) at 10 mW/cm.^{2} for two hours daily for from 10 to 30 days. Body temperature in rats exposed under these conditions increased by 1° C. within the first 30 minutes of exposure, and remained at this level through the exposure period. Hematocrit, hemoglobin concentrations, and circulating erythrocytes in the exposed rats increased during the 30-day exposure, and fluctuations in the various leukocyte populations also fluctuated—changes that were thought to be due to the thermal effect of microwaves. In a more recent study, Djordjevic et al.[17] found no significant difference in any of several hematologic indices among rats which were exposed to 2,400

MHz. (CW) microwaves at 5 mW/cm.^{2} for one hour daily for 90 days.

Czerski[18] reported alterations in ferrokinetics in rabbits exposed to 2,950 MHz. continuous or pulse-modulated microwaves at 3 mW/cm.^{2} for two hours daily from 37 to 79 days. Erythrocyte production, measured by ^{59}Fe incorporation, significantly decreased in exposed animals but without change in erythrocyte count, hemoglobin level, or hematocrit. In another study, Czerski et al.[19] reported that the exposure of mice to 2,950 MHz. pulse-modulated microwaves at 1 mW/cm.^{2} at various times of the day caused changes in the normal circadian rhythm of bone marrow cell mitoses. Czerski et al.[19] suggested that microwaves may act as a mitotic stimulus for stem cells and particularly lymphocytes. The observed effects depended both on the time of the day when exposed and on the cell series. No differences were observed in rectal temperatures between the exposed mice and controls.

More recently, Rotkovska and Vacek[20] reported changes in hematopoietic cell populations of mice following a single five-minute exposure to 2,450 MHz. (CW) microwaves at an intensity of 100 mW/ cm.^{2} The response of microwave-exposed mice was compared to that of mice placed in a chamber at 43° C. for five minutes. Both treatments caused a rise in rectal temperature of over 2° C. Leukocytosis occurred both in mice exposed to microwaves and those exposed to heat but the time course for the leukocytosis differed: following microwave exposure, the total cell volume of the bone marrow and spleen decreased and the number of hematopoietic stem cells in bone marrow and spleen, as measured by the colony-forming unit assay, increased. Incorporation of ^{59}Fe in the spleen decreased 24 hours after microwave exposure, but the heat exposure decreased colony-forming units in bone marrow and spleen and increased the percentage of ^{59}Fe incorporation. Rotkovska and Vacek[20] concluded that the different effects on the hematopoietic stem cells of microwaves and externally applied heat suggests that biological effects caused by high intensities of NEMR are not necessarily related only to increased internal temperature. They indicated that their results suggest a possible direct effect. Their study is significant because it demonstrates a marked difference in the kinetic response of the hematopoietic system to two forms of heat stress. Consequently, these differences need to be considered in the interpretation of NEMR-induced changes in the hematopoietic system.

Rotkovska and Vacek[21] studied the effect of microwaves on the recovery of hematopoietic tissue following exposure to x-irradiation. Mice exposed to whole-body x rays at 300 to 750 rads were subsequently exposed to 2,450 MHz. (CW) microwaves at different time intervals for five minutes at 100 mW/cm.^{2} The combined treatment accelerated the recovery of hematopoietic tissue, heightened erythropoiesis and myelopoiesis, and increased survival rate compared to x-irradiated mice. The increase in the number of hematopoietic endogenous colonies in the spleens of the x-irradiated mice followed microwave exposure supports Rotkovska and Vacek's[20] earlier observation of an elevation in the number of stem cells in the spleens of intact mice after microwave exposure alone. These investigators[21] suggested that microwaves may influence mechanisms that activate the stem-cell pool either by enhancing repair of sublethal radiation damage or by increasing proliferative capacity of stem cells that survive x-irradiation. This acceleration of the repair processes of radiation damage of hematopoietic cells following thermogenic doses of microwaves was thought to depend upon the stage of intracellular repair at the time of microwave exposure.[21] In earlier work, Michaelson et al.[22] reported that simultaneous exposure to x rays and microwaves (2,800 MHz., pulse-modulated, 100 mW/cm.^{2}) accelerated recovery of hematopoietic function in dogs. Exposure of x-irradiated (725 to 950 R) Chinese hamsters to microwaves (2,450 MHz. (CW), 60 mW/cm.^{2} for 30 minutes) five minutes following x-irradiation significantly increased the x ray $LD_{50(30)}$ compared to x rays alone or microwave exposure followed by x rays.[23] Lappenbush et al.[23] reported that the radioprotection of microwaves is associated with a delayed drop in the number of circulating white blood cells, reduced period of low cell density, and complete replenishment of white blood cells within 30 days following the dual treatment. Exposure to microwaves alone or in combination with x-ray exposure increased the relative number of neutrophils, reduced the relative number of lymphocytes, and slightly increased the number of circulating red blood cells. Animals exposed first to microwaves and then to x rays demonstrated more severe leukocyte changes than x-irradiated hamsters because leukocyte counts dropped faster and the animals developed leukopenia. These workers[23] suggested that the radioprotective effect of microwaves may be due to a thermal mechanism involving surviving bone marrow cells. These findings[20-23] indicate that NEMR at levels sufficiently intense to cause thermal loads in animals are capable of radioprotection against x rays. How this effect is accomplished is unknown.

The effect of NEMR whole body exposure on circulating blood cells of developing rats has been studied in my laboratory.[24,25] Rats were exposed pre- and postnatally to 425-MHz. (CW) at 10 mW/cm.^{2} four hours daily for up to 40 to 41 days after birth. Because of growth of animals during this time, specific absorption rates (SARs) ranged from three to seven mW/g. Absolute neutropenia and relative lymphocytosis was observed in exposed compared to sham-control rats,[24] but these changes were not consistently reproduced. Rats exposed under the same regimen but to 2,450 MHz. (CW) at 5 mW/cm.^{2}, SAR = 1-5 mW/g., showed no difference in circulating erythrocyte count, total and differential leukocyte counts, hematocrit, and hemoglobin concentration when compared to sham-controls.[25] Hamrick and McRee[26] examined the effect of NEMR on developing birds. Quail eggs were exposed for 24 hours on the second day of incubation to 2,450 MHz. (CW) at 30 mW/cm.^{2}, SAR = 14 mW/g. At 24 to 36 hours after hatching, quails were examined for gross deformities, changes in organ weight, and hematological changes. No significant effects due to microwave exposure were detected.

In another study,[27] we exposed mice to 2,450 MHz. (CW) at 30 mW/cm.^{2}, SAR = 22 mW/g., for 30 minutes on 22 consecutive days. These mice showed no significant differences in circulating erythrocyte counts, total and differential leukocyte counts, hematocrit and hemoglobin concentration compared to sham-controls. Under the conditions of this study, microwave radiation did not elevate the rectal temperatures of exposed mice significantly more than among sham-controls. In contrast, when mice were exposed to thermogenic (2 to 4° C. rise in rectal temperature) levels of NEMR at 26-MHz. (CW), 8,610 mW/cm.^{2}, decreased numbers of circulating lymphocytes and increased circulating neutrophils were observed immediately following exposure.[28] Liburdy[28] reported that this shift reached its peak three hours after exposure. Pre-exposure levels of circulating lymphocytes and neutrophils returned to normal from 55 to 96 hours following exposure. On the other hand, mice exposed to high temperatures (79° C.) in a vented, dry-air oven showed an increase in circulating lymphocytes and neutrophils for 12 hours following exposure. It appears, therefore, that the response of circulating leukocytes to thermal loads depends on how heating of the body is accomplished. These results are similar to those reported by Rotkovska and Vacek,[21] and indicate that the heating properties of NEMR fields are unique compared to other modes of tissue heating.

In summary, thermogenic levels of NEMR elicit changes in the hematopoietic system that can for the most part be attributed to thermal stress response. Changes in the blood of animals exposed to NEMR at levels of intensity insufficient to increase body core temperature suggest a similar stress-response mechanism. Failure to record an increase in core temperature does not exclude the possibility that the animal can compensate for the added heat by thermoregulatory mechanisms. The response elicited by NEMR, however, seems to differ from that of conventional heating due to the unique heating property of this radiation. More sensitive methods to assess thermal stress responses are needed to explain observed hematologic phenomena more fully.

IMMUNOLOGY

In vivo studies. One of the most consistent findings of NEMR-induced changes in the hematopoietic system is increased lymphocyte formation and activity following exposure of several species to various frequencies of microwaves.[14,15,18,20]

Consequently, there have been several studies of the effects of NEMR on lymphocytes and the immune system. In a study by Czerski,[18] mice were exposed for six hours daily to 2,950 MHz. pulse-modulated microwaves at 0.5 mW/cm.^{2} for six or 12 weeks. After six weeks the relative number of lymphoblasts in the lymph nodes of exposed mice increased considerably. In another experiment,[18] rabbits were exposed two hours daily, six days weekly for six months to 2,950 MHz. pulsed microwaves at 5 mW/cm.^{2} Peripheral blood lymphocytes from these animals when cultured for seven days *in vitro* underwent increased ''spontaneous lymphoblastoid transformation.'' Maximum increases occurred after one or two months of exposure, returned to base line, and rose again one month after irradiation had been terminated. Miro et al.[29] exposed mice to 3,105 MHz. pulsed microwaves continuously over a 145-hour period at an incident power of 2 mW/cm.^{2} Lymphoblastic cells in the spleen and lymphoid areas of exposed mice increased. A comparable response was observed[30] for lymphocytes cultured from Chinese hamsters exposed to 2,450 MHz. (CW) microwaves for 15 minutes on five consecutive days at 5 mW/cm.^{2}, SAR = 2.3 mW/g. Transformation to lymphoblastoid forms was maximum in cultures from hamsters exposed to 30 mW/cm.^{2}, SAR = 13.8 mW/g. This power density caused a 0.9° C. rise in rectal temperature of exposed hamsters. Mitosis of lymphocytes cultured in the presence of the mitogen phytohemagglutinin (PHA) was depressed in cells obtained from hamsters exposed to 5, 15, 30, or 45 mW/cm.^{2} Cytogenic analysis of these lymphocytes revealed no difference in chromosomal aberrations between exposed and control hamsters. The significance of this study is that both enhancement of transformation and inhibition of mitosis were evident at 5 mW/cm.^{2}, a power density which caused no significant change in rectal temperature. These effects were transient and reversible with a return to control levels after 5 to 10 days.[30]

Prince et al.[31] reported a similar effect in rhesus monkeys, where they found an enhanced mitotic response of peripheral blood lymphocytes stimulated *in vitro* with PHA from monkeys three days following a 30-minute exposure to 10.5-MHz. pulsed radiation at 1,320 mW/cm.^{2} Enhancement of mitosis of cultured lymphocytes from monkeys similarly exposed to 19.27- and 26.6-MHz. were also reported, and increases in circulating lymphocytes from 4 to 47% above pre-exposure levels. At a frequency of 26.6 MHz., the rectal temperature of monkeys following exposure increased by 2.5° C. above pre-exposure levels. A frank thermal stress response at this frequency is the most plausible explanation for these results.

The particular susceptibilities of lymphocytes to NEMR described above have led to examination of the effects of nonionizing radiation on the immune system. For example, Czerski[18] reported that mice exposed for six weeks to 2,950 MHz. pulsed microwaves at 0.5 mW/cm.^{2} had significantly greater numbers of antibody-producing cells and higher serum antibody titers following immunization with sheep red blood cells (SRBC). Mice exposed for 12 weeks did not show this increased responsiveness.[18] More recently, Wiktor-Jedrzejczak et al.[32-34] exposed mice in a rectangular wave guide to 2,450 MHz. microwaves for 30 minutes at an average dose rate near 14 mW/g. At 3, 6, 9, and 12 days following single or multiple exposure, mice were tested for: the relative frequency of T (thymus-derived) and B (bone marrow-derived) splenic lymphocytes, the functional capacity of spleen cells to respond to T-and B-cell-specific mitogens, and ability to respond to SRBC or dinitrophenyllysine-Ficoll (DNP-lys-Ficoll). A single 30-minute exposure induced a significant increase in the proportion of complement-receptor positive lymphocytes (CRL^+) in the spleens of mice which peaked six days following exposure. This effect was further enhanced by repeated (three times) exposures which also produced a significant increase in the proportion of immunoglobulin positive (Ig^+) spleen cells.[33] A significant increase in the proportion of Fc receptor positive (FcR^+) cells in the spleens was observed seven days following single exposure for 30 minutes SAR = 13.7 mW/g. However, no change in the number of Ig^+ cells in spleens of these mice was observed.[34] The type and combination of surface receptors (CR, Ig, Fc) expressed on splenic B-cells represent different maturational stages in B-cell development. Wiktor-Jedrzejczak et al.[32-34] were unable to demonstrate any change in the total number of theta positive (θ^+) T-cells in the spleens of mice following a single or multiple exposure to 2,450 MHz. microwaves, nor change in *in vitro* spleen-cell response to stimulation by the T-cell-specific mitogens PHA and conconavalin A (Con A).[32] The response of spleen cells to pokeweed mitogen (PWM), which stimulates both T- and B-cells, was also unchanged. The response to the B-cell-specific mitogens lipopolysaccharide (LPS), polyinosinic polycytidylic acid (Poly I·C), and purified protein derivative of tuberculin (PPD), however, significantly increased over controls following a single exposure.[32] These results agree with the observed changes in the proportion of cells bearing different surface markers. Wiktor-Jedrzejczak et al.[32] noted that microwave irradiation did not stimulate lymphoid cell proliferation per se, but appeared to act as a polyclonal B-cell activator, which led to early maturation of noncommitted B-cells. These investigators also found a significant decrease in the primary immune response to SRBC, a thymus-dependent antigen, in mice immunized just prior to their first exposure to microwaves. They suggested that this decreased response may result from nonspecific microwave stimulation of some cells to mature before they are activated by antigen (SRBC), thereby increasing the proportion of unresponsive cells.[32]

We have[27] exposed mice to 2,450 MHz. (CW) under far field conditions for periods of 15 or 30 minutes daily for up to 22 consecutive days at power densities ranging from 5 to 35 mW/cm.^{2}, SAR = 4 to 25 mW/g. Splenic lymphocyte function was assessed by the *in vitro* mitogen-stimulated response assay as measured by ^{3}H-thymidine incorporation following culture in the presence of T-(PHA, Con A, PWM) or B-(LPS, PWM, PPD) mitogens. Frequencies of T (θ^+) and B (CRL^+) splenic cells and the primary immune response of mice to SRBC were also studied. No difference in the response to mitogens, SRBC, or in the frequency of T- or B-cells was observed in microwave-exposed compared to sham-exposed mice. These experiments were performed in an attempt to reproduce, in part, the observations of Wiktor-Jedrzejczak et al.[32-34] Failure to repeat these observations was originally suggested as due to the different exposure systems,[27] but this discrepancy may also be due in part to the strain of mice used by these two different groups. Wiktor-Jedrzejczak et al.[32-34] used CBA/J mice while we[27] used BALB/C mice. Recent work (Dr. C. Schlagel, personal communication) has shown that the microwave-induced effect observed by the former group is strain specific in that it can be induced in CBA/J mice but not BALB/C mice. The reason for this strain specificity is unexplainable at this time.

Liburdy[35] recently reported that changes in splenic lymphocyte populations similar to those observed by Witkor-Jedrzejczak et al.[32-24] can be produced by exposure of mice to thermogenic levels of 26 MHz. radiofrequency radiation. When mice were exposed to 26 MHz. at an intensity which produced a 2 to 3° C. rise in rectal temperature, splenic T- and B-lymphocytes relatively increased. Similar responses were induced following administration of methyl prednisolone sodium succinate, results that suggest that these radiofrequency-induced changes represent a stress phenomenon.

Microwave effects on the development of the immune response have been studied in two laboratories. We[24,25] exposed rats starting on day six of gestation through 41 days from birth to 2,450 MHz. (CW) at 5 mW/cm.^{2}, SAR = 1 to 5 mW/g. Their lymphocytes responded to a significantly greater extent than those from control animals following stimulation *in vitro* with T- or B-cell mitogens.[25] A similar increase in lymphocyte responsiveness was seen in lymphocytes from rats exposed to 425 MHz. (CW).[24] In this study, rats were exposed pre- and postnatally to 425 MHz. microwaves at 10 mW/cm.^{2}, SAR = 3 to 7 mW/g., for up to 41 days following birth. These two studies[24,25] suggest that long-term exposure of developing rats to microwaves may cause the increased responsiveness of cultured lymphocytes. These results resemble other reported changes in lymphocyte responsiveness following NEMR exposure.[18,30-34] Hamrick et al.[36] examined the humoral immune response of Japanese quails exposed to microwaves during embryogenesis. Fertile quail eggs were exposed to 2,450 MHz. (CW) microwaves at 5 mW/cm.^{2}, SAR = 4.03 mW/g., throughout the first 12 days of development. At five weeks of age quails were immunized with SRBC and the levels of anti-SRBC antibodies were determined. No difference was observed in antibody titers of exposed and sham-exposed quails. Further, microwave exposure did not significantly alter the weights of the bursa of Fabricius (site of B-cell production in birds) and spleen.

NEMR-induced effects on the phagocytic leukocytes of animals have been reported by Szmigielski et al.[37] Rabbits were exposed to 3,000 MHz. for six hours daily for six weeks to three months at 3 mW/cm.[2] After the last exposure to microwaves, rabbits were infected with an intravenous injection of virulent *Staphylococcus aureus*. At periods before and after infection, functional tests of granulopoiesis documented decreased production of mature granulocytes in response to infection in microwave exposed rabbits which were more seriously ill than controls.

Exposure of laboratory animals to NEMR can change the functional integrity of lymphocytes that are important in the immune defense system of man and animals. The significance of the changes caused by NEMR is difficult to interpret. While some studies indicate that NEMR increases responsiveness of lymphocytes[18,24,25,31-35] and potentiates the immune response to antigen,[18] others indicate depressed responsiveness.[30,32,35,37] In most cases these alterations can be attributed to stress-type responses because similar changes are observed at thermogenic levels of NEMR[30,31,35] or following administration of glucocorticoids.[35] Effects observed at lower levels of NEMR also appear to involve some type of stress-response mechanism. Fully to evaluate these low-level effects, a better understanding of the interaction of the immune and thermoregulatory systems is needed.

In vitro studies. Several studies have attempted to determine whether *in vitro* exposure of lymphocytes with NEMR leads to "direct" changes in their metabolic or functional states. In an early study, Stodolnik-Baranska[38] exposed human lymphocytes in culture to 3,000 MHz. pulsed microwaves at 7 or 14 mW/cm.[2] Lymphocytes were irradiated for four hours daily at 7 mW/cm.[2] for three to five days, while those exposed to 14 mW/cm.[2] were irradiated for 15 minutes for three to five days. After five days in culture, the microwave-exposed cells had undergone a fivefold increase in blast transformation compared to controls. Czerski[18] attempted to repeat this experiment but found the results poorly reproducible. In a more recent study, Baranski and Czerski[39] reported that exposure of human lymphocytes to 10,000 MHz. at power densities between 5 and 15 mW/cm.[2] could induce lymphoblastoid transformation. At power densities below 5 mW/cm.[2] this effect was not observed, while at power levels above 20 mW/cm.^{2} cell viability decreased. The induction of blast transformation depended upon stopping the exposure (5 to 15 mW/cm.^{2}) at the moment when the temperature of the medium reached 38° C. These results suggest that the microwave-induced blast transformation is due to a thermal effect.

Similar increases in the lymphoproliferative response of cells exposed to temperatures greater than 37° C. have been reported. Ashman and Nahmais[40] reported that human lymphocytes, when cultured at 39° C. with the mitogens PHA or Con A, showed an enhancement and earlier onset of ^{3}H-thymidine incorporation compared with cultures incubated at 37° C. In a similar study, Roberts and Steigbigel[41] reported that the *in vitro* human lymphocyte response to PHA and the common antigen streptokinase-streptodornase was enhanced at 38.5° C. relative to 37° C. Smith et al.[42] reported that the *in vitro* response of human lymphocytes to PHA, Con A, PWM, and allogeneic lymphocytes in mixed lymphocyte (MLS) was markedly enhanced by culture at 40° C. compared to 37° C. These studies demonstrate the need to monitor and to control the temperature of cultures exposed to NEMR. Without adequate temperature data, it is virtually impossible to accept *in vitro* effects as due to NEMR itself.

Failure to increase culture temperature during or following *in vitro* NEMR exposure has been shown in several studies not to affect the proliferative response of lymphocytes. Holm and Schneider[43] exposed human lymphocytes, cultured in the presence of PHA, to 27.12-MHz. at an estimated effective radiating power of 10 W. No substantial differences were noted between 27.12 MHz. exposed cultures and controls regarding DNA synthetic index, growth, or mitotic index. Culture temperatures did not exceed those of controls (37° C.) by more than 1° C. In my laboratory[44] murine splenic lymphocytes were exposed to 2,450 MHz. (CW) microwaves for one, two, or four hours at 10 mW/cm.^{2}, SAR near 19 mW/g. Following irradiation, the temperature of the exposed cultures did not differ significantly from controls and cell viability was unchanged. Following irradiation, cells were cultured for 72 hours in the presence of T- or B-cell mitogens and the proliferative response was measured by ^{3}H-thymidine incorporation. No difference was found in the blastogenic response of microwave-exposed and sham-exposed spleen cells to any of the mitogens employed. In a similar experiment, Hamrick and Fox[45] exposed rat lymphocytes to 2,450 MHz. (CW) microwaves for four, 24, or 44 hours at 5, 10, or 20 mW/cm.^{2}, SAR = 0.7, 1.4 and 2.8 mW/g.

respectively. Unlike the previous studies,[18,38,43,44] Hamrick and Fox[45] exposed whole blood preparations to microwaves. Transformation of unstimulated or PHA-stimulated lymphocytes was measured using ^{3}H-thymidine. No significant differences were found in the proliferative capacity of lymphocytes from exposed and control cultures. The effects of 2,450 MHz. CW microwave radiation on the growth and viability of cultured human lymphoblasts was studied by Lin and Peterson.[46] Human lymphoblasts (lines Daudi and HSB_2) were exposed to 2,450 MHz. (CW) microwaves in a waveguide for 15 minutes at incident power densities of 10 to 500 mW/cm.^{2} The corresponding rates of energy absorption were up to 1,200 mW/g. No temperature increase was found, even at the highest power density in the capillary tube which held the cell suspension in the waveguide. No change was observed in the viability or growth of microwave-exposed lymphoblasts compared to controls—further evidence that in the absence of heating, no change in lymphocyte activity occurs following NEMR exposure *in vitro*.

In vitro exposure of macrophages to 2,450 MHz. has been reported to depress phagocytosis by Mayers and Habeshaw.[47] Monolayer cultures of mouse peritoneal macrophages were perfused with suspensions of human erythrocytes while simultaneously exposed to 2,450 MHz. microwaves at 50 mW/cm.^{2} The energy absorbed as heat by the sample was 15 J/min. The phagocytic index of exposed cultures was significantly lower than control after a 30-minute exposure. Macrophage phagocytic activity was restored to normal if the microwave irradiation was discontinued. When the microwaves were on, a 2.5° C. temperature increase was observed, but the final temperature in any given experiment did not exceed 36.2° C. These investigators concluded that the observed depression of phagocytosis in irradiated cultures was not thermally induced and that the 2.5° C. rise in temperature during irradiation would have been expected to enhance rather than depress phagocytosis because optimal phagocytosis occurs at a temperature of 38.5° C.[47] The mechanism by which this effect is caused is not known, but heating effects are difficult to dismiss at such a high power density. While the temperature of the suspension medium did not exceed 36.2° C., thermal gradients of much higher temperature would be expected at the macrophage-glass interface.

A microwave-induced effect on granulocyte integrity and viability was reported by Szmigielski,[48] who exposed rabbit granulocytes *in vitro* to 3,000 MHz. (CW) microwaves at 1 or 5 mW/cm.^{2} for 15, 30, or 60 minutes. Cultures exposed at 5 mW/cm.^{2} for 30 or 60 minutes had increased cell death as demonstrated by an increase in nigrosine staining and enhanced liberation of lysosomal enzymes. Exposure to 1 mW/cm.^{2} fields did not cause increased cell death but led to a partial liberation of hydrolases. No change was observed in the temperature of microwave-exposed cultures. The liberation of granulocyte acid phosphatase and lysozyme was observed in cell suspensions exposed to either 1 or 5 mW/cm.^{2} and both exhibited a time- and dose-dependent relation. Szmigielski[48] suggested that low-level microwaves may affect the cellular membrane. The possible production of thermal gradients produced in the culture vessels by NEMR might explain these effects.

NEMR-induced hyperthermia studies. Over the past several decades increasing evidence for the beneficial effects of partial or whole-body hyperthermia has accumulated. Several studies have demonstrated that NEMR-induced hyperthermia may benefit a variety of diseases, including cancer. For example, LeVeen et al.[49] reported that radiofrequency therapy (13.56 MHz.) at power densities of 1,000 to 4,000 mW/cm.^{2} for up to 30 minutes at a time produced tissue necrosis or substantial regression of cancer in 21 patients. Combined radiotherapy (x rays) and NEMR-induced hyperthermia (434 MHz.) is reported to cause a 94% resolution of primary and secondary lesions and to increase the three-year survival rate of patients with advanced head and neck cancers.[50]

While in most cases destruction of heated tissue is the ultimate goal, such applications of NEMR have often led to changes in the immune response. For example, Shah and Dickson[51] reported that following local heating of VX2 (carcinoma) tumor-bearing rabbits with a radiofrequency generator (13.56-MHz.), tumor regression and host cure were observed in 70% of the rabbits. Intratumor temperatures of 47-50° C. were achieved within 30 minutes. Along with tumor regression, cell-mediated immunity, as measured by skin reactivity to tumor extract and dinitrochlorobenzene, markedly increased. A 100-fold increase in serum levels of antitumor antibody and increased response to antigen bovine serum albumin were also observed. Total-body hyperthermia, however, led to temporary restraint of tumor growth, followed by a return to an exponential increase in tumor volume and rapid death of the rabbit. This course of events following whole-body hyperthermia was accompanied by abrogation of the enhanced cellular and humoral immune responsiveness observed following radiofrequency-induced local heating.

Szmigielski et al.[52] reported that local heating (43° C.) of the Guérin epithelioma in Wistar rats by 2,450 MHz. (CW) microwaves both inhibited tumors and stimulated the immune reaction against the tumor. Nonspecific immune reactions stimulated by this treatment were the antibody response to BSA, high reactivity of spleen lymphocytes to the mitogen PHA, and increased serum lysozyme levels as a measure of macrophage activity. Tumor-specific reactions observed were increased cytotoxicity of spleen cells and peritoneal macrophages to cultured tumor cells. Similar results were reported by Marmor et al.,[53] who exposed tumors in mice to local 1,356 MHz. radiation. EMT-6 tumors were found to be highly sensitive to cure by radiofrequency heating. The cure rate was a function of temperature and duration of exposure: a five-minute exposure at 44° C. cured almost 50% of the tumors. To determine the effectiveness of radiofrequency heating on tumor regression, tumor-cell-survival studies were done on EMT-6 tumors treated in situ. Cell inactivation by radiofrequency heating was similar to that for hot water bath heating. The results indicated that direct cell killing could not account for the observed cures, and these investigators[53] suggested that hyperthermia may stimulate a tumor-directed immune response.

Szmigielski et al.[54] exposed mice bearing transplanted sarcoma-180 tumors for two hours daily on the first through 14th day after transplantation to 3,000 MHz. microwaves at 40 mW/cm.^{2} This exposure led to a 3° to 4° C. increase in rectal temperature, and resulted in a reduction of tumor mass by approximately 40%, a reduction enhanced when microwave hyperthermia was combined with Colcemide, Streptolysin S, or both. Colcemide enhances the inhibiting effect of microwaves on proliferation of cells *in vitro*[55] and Streptolysin S is an antineoplastic substance. Szmigielski et al.[52] suggested that immunostimulation is important in the complex inhibition of tumor growth by increased temperatures.

While many have heralded local and systemic hyperthermia as a possible cancer treatment, either alone or in combination with drugs or ionizing radiation, there is evidence that hyperthermia may enhance the dissemination of certain cancers and abrogate the immune response. For example, Dickson and Ellis[56] reported that local hyperthermia (hot water bath immersion) of implanted solid Yoshida sarcomas in the feet of rats can enhance dissemination of this sarcoma if local heating is inadequate for complete tumor destruction. Walker et al.[57] reported a dramatic promotion of metastasis by local heating (water heater) of the C3H mouse mammary carcinoma. Shah and Dickson[58] exposed normal rabbits to either radiofrequency-induced (13.56 MHz.) or watercuff local hyperthermia of thigh muscles which were maintained at 42° C. for one hour on three consecutive days. No alteration in the response to dinitrochlorobenzene challenge was observed. However, the humoral immune response to bovine serum albumin was significantly depressed. This response was independent of the method and degree of heating. The results suggest that B-lymphocytes are more susceptible to hyperthermic damage than are T-lymphocytes.

Discrepancies in the response of various species with different neoplasms to NEMR-induced or heat-induced hyperthermia indicates that more work in this area is needed. It is not known whether NEMR-induced hyperthermia affords the host more immunologic benefit than conventional heating of tissue. What is certain, however, is that NEMR-generating devices may contribute to cancer treatment to providing a means to generate intense heat in a localized defined area of tissue.

Discussion

It is apparent that partial or whole-body exposure of animals to NEMR may lead to a variety of changes in their hematologic and immunologic systems. These changes are often transient, with blood counts or other responses returning to normal either immediately or soon after cessation of exposure. However, inconsistencies in these responses to NEMR adds to the ambiguity of the results. In most reports, the thermal influence of NEMR on the observed alterations is obvious, and increased body core temperature and hematologic and immunologic changes are directly correlated in several reports. Observed results are explainable in terms of NEMR-induced thermal stress. Several reported effects of NEMR on the hematologic and immune systems, for example, are very similar to those following a stress response involving the hypothalamic-hypophyseal-adrenal axis or following administration of glucocorticoids.[59-67] Other observed changes, however, are more difficult to explain on a thermal-stress basis, primarily because of a lack of sensitive techniques to detect subtle stress responses. Mere lack of a rectal temperature increase following exposure to NEMR, however, does not exclude a possible thermal interaction which the animal can compensate and control. Localized heating or "hot spots" in organs critical to the hematopoeitic and immune systems may occur from production of thermal gradients unique to radiofrequency energy absorption by biological systems. Interpretation of NEMR effects on the blood and blood-forming systems depends to a great degree on the absorption characteristics of biological materials and the thermoregulatory system of the irradiated individual. Many factors affect the dose rate of NEMR to the body, organ, or tissue, including the frequency and wave length, field intensity, direction of wave propagation, the mass and shape of the body, and orientation of the body in the NEMR field. The rate at which energy is absorbed per unit of body mass is called the specific absorption rate (SAR) or the dose rate. The rate of whole body energy deposition varies with frequency and is greatest at the resonant absorption frequency. In addition to other factors, the resonant frequency for an individual object depends on its size and mass. For example, an adult human in free space will maximally absorb NEMR at a frequency between 70 and 80 MHz., while the resonant frequency for a mouse is about 2,450 MHz.[68] Unfortunately, few of the reports cited above[24-28,30,32-36,44-46] give the SAR measurements, which are extremely important in the evaluation of biological effects. Because of discontinuities in the dielectric properties of tissues, standing waves with the concomitant production of localized heating or "hot spots" are produced by NEMR fields. Both the frequency and the conductivity and permittivity of irradiated tissue affect the propagation and absorption of NEMR in tissue. For example, blood, body fluids, skin, muscle, brain and internal organs that contain large amounts of water will absorb more NEMR than such tissue with low water content as bone, fat, and tendon.[69] Consequently, actual distribution of energy within a body and the specific absorption rate must be determined before one can legitimately ascribe an observed change as due to "direct" interaction of NEMR fields in the absence of some form of thermal involvement.

The interpretation of NEMR-induced changes in the hematologic or immunologic systems also depends upon the ambient exposure conditions and thermoregulatory capacity of the exposed individual. The dissipation of NEMR-induced thermal loading among species depends upon the area of the body exposed, duration of exposure, efficiency of heat elimination which includes thermoregulation and blood flow, and such ambient environmental conditions as temperature, humidity, and air flow. Humans are relatively good at thermoregulation, whereas such small rodents as mice are poor thermoregulators. This is an important consideration in attempting to extrapolate changes observed in rodents following NEMR exposure and what might be expected to occur in humans. Consideration of frequency scaling and the equal whole-body SAR concept are essential to attempt extrapolation of NEMR effects between animals and humans. At best, this is only a gross approximation, because sizes and shapes affect the distribution of NEMR energy within bodies. Therefore, comparisons of the distribution of energy in an animal to that of a man is very difficult and consequently extrapolation of NEMR-induced effects becomes even more difficult.

Unfortunately, the few available clinical and epidemiological studies are of limited usefulness in our attempt to evaluate the health effects of NEMR. For the most part, the studies cited above are inadequate to assess effects on the hematologic and immunologic systems of humans exposed to NEMR. These studies lack sufficient detail of exposure history and usually lack adequate control groups. While none of the studies report detrimental hematologic changes, one wonders why more and better conducted studies have not been done. Several occupational groups would be very well suited for ongoing clinical studies in that NEMR exposure records could be kept and adequate controls employed. Three prime candidates for such studies would be radiofrequency tower maintenance personnel, personnel who operate radiofrequency sealers, and diathermy unit operators. However, without further clinical studies, it is difficult to make a definitive statement on the human health effects of NEMR.

In conclusion, high intensity NEMR fields induce thermal loads in animals which in turn affect the hematologic and immunologic systems. These responses are similar if not identical to responses elicited in animals following a stressful encounter or administration of glucocorticoids. More subtle NEMR-induced heating may account for the biological effects reported in the absence of an increase in body-core temperature. These effects, similar to stress-type responses, may be attributed to the unique heating property of NEMR. It is not certainly known that these effects are necessarily the hallmark of changes in the hematologic or immunologic systems that will eventually lead to disease or, for that matter, to a more responsive immune system.

Convincing evidence for a direct interaction of NEMR with hematopoietic cells *in vitro* or *in vivo* is not available. Evidence is increasing that NEMR fields may interact and cause alterations at the membrane level of organization in nervous tissue,[70,71] but no such clear evidence is available for blood cells. This does not exclude the possibility of such interactions, and continued research in this area of mechanism of action is necessary. What appears to be evident is that the hematological and immunologic systems are sensitive to NEMR fields. The relative sensitivities of these systems for NEMR fields needs to be determined so that the potential health risk to humans can be better evaluated. Because of lack of understanding of the effects of long-term, low-level exposure to NEMR on the hematologic and immunologic systems of man and animals, future studies are needed. Through such studies it is hoped that a reasonable understanding of NEMR effects can be achieved so that unfounded restrictions on the beneficial uses of nonionizing radiation are avoided.

Disclaimer

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RECAPITULATION: BIOMEDICAL EFFECTS*

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THE ever increasing environmental levels and biomedical applications of microwave and radiofrequency radiation dictates the need for a thorough understanding of effects on human beings. Recent investigations, almost exclusively conducted with experimental animals and model systems, have revealed a number of previously unknown exposure effects which have emphasized the fact that our present knowledge in this area, especially in the case of exposure to low-intensity fields, is not advanced to a state at which health effects may be adequately assessed.

It is well known that the primary mode of interaction of alternating electromagnetic fields at microwave and radiofrequencies is induced rotation and translation of charged or polar molecules and ions. Water, the predominent polar molecule in tissue, accounts for the primary mode of electromagnetic energy absorption at microwave frequencies, a consequence of which is that tissue heating from microwave radiation is nonuniform as relatively greater amounts of heat is produced in tissue of high water content, such as muscle, than in low water content fatty tissues. Because microwave and to a lesser extent radiofrequency radiations are also reflected within the human body, a highly nonuniform pattern of energy absorption results, a phenomenon used to advantage, for example, in selective heating of deep-lying muscles in microwave diathermy. Complex patterns of absorption, however, greatly complicate the interpretation of *in vivo* biological responses to such fields because detailed internal energy distributions are difficult to determine and consequently dosimetry has generally not been accurate in the area of microwave bioeffects.

Another obvious confounding factor encountered in assessment of microwave and radiofrequency bioeffects is the variation in sensitivity of various tissues to field effects. High intensity microwave and radiofre-

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quency fields are currently employed in experimental hyperthermic treatment of cancer. Tumor tissue, if relatively avascular, is selectively heated compared to adjacent normal tissue, a consequence of which is that tumoricidal temperature elevations may be reached without damage to normal tissue. Selective heating of other relatively avascular tissue, however, damages normal tissue, as documented by development of cataracts in experimental animals exposed to microwave fields inducing retrolental temperature rises to 42°C. or higher. In spite of the degree of uncertainty surrounding exposure parameters, cataract induction appears to be the only reported irreversible effect of accidental overexposure of human beings to microwave radiation.

Microwave cataractogenesis has generally been assumed to be a consequence of excessive localized thermal stress due to exposure to high intensity (i.e., power densities in excess of 100mW/cm.^{2}) microwave fields. Field intensities of this magnitude produce convulsions and death from hyperpyrexia in experimental animals and, although dose-effect relations are not completely determined, tissue thermal denaturation appears to be the mechanism for such effects. The primary current uncertainty concerns the biomedical effects of microwave and radiofrequency fields at intensities of 10mW/cm.^{2} or less that result in minimal or undetectable levels of thermal stress. If microwave and radiofrequency radiation at such intensities do not raise core temperatures beyond physiological tolerance levels, what are the mechanisms responsible for such effects?

Before considering this question, it is appropriate to describe selected low-intensity microwave and radiofrequency effects. Functional alterations predominate among such effects in human beings and experimental animals and apparently involve the central nervous system. These effects are associated with the lowest exposure levels and have been under experimental and epidemiological investigation for more than two decades. Recently it has been reported that relatively low-intensity exposure also alters the hematopoietic and immunological systems. Microwave and radiofrequency effects on the central nervous system hematopoietic-immunological systems will be described as representative of low field intensity phenomena, although many other exposure effects have been reported involving, for example, the neuroendocrine system, chromosomal aberrations and mutagenesis, teratogenesis and effects on growth and development. Data are not adequate to draw conclusions, but these latter classes of effects generally involve higher exposure intensities than central nervous system effects and possibly also those on the hematopoietic-immunological systems.

Central nervous system disturbances in progressive stages related to duration of employment have been reported among occupationally exposed workers.[1] A neurasthenic syndrome characterized by circulatory and digestive disturbances and subjective complaints of fatigue, sleeplessness, and headache characterize the first stage, followed by similar subjective alterations with some organic damage to motor systems that in some reports progresses to a final encephalopathy.[1] Electroencephalographic changes, typically an increase in slow rhythms of high amplitude, have also been reported in exposed workers.[1] The electroencephalographic, clinical, and biochemical changes suggest localized effects in the mesodiencephalic region of the brain.[1] KlimKova-Deutschova[1] proposes that these changes implicate nonuniform pulse-modulated microwave energy absorption in the brain leading to thermally-mediated functional changes. The validity of such mechanisms is difficult to assess because of lack of sufficient information on thermophysiology of the brain, but it must be acknowledged that the spatial and temporal characteristics of microwave heating of the brain differ markedly from any other type of thermal stress, suggesting the possibility that normal physiological compensatory mechanisms would not be able to counteract the unique stress imposed by microwave absorption. The difficulties encountered in microwave and radiofrequency dosimetry and field characterization preclude establishment of any direct relation between such effects and exposure intensity, but available evidence suggests that significant degrees of brain heating would not be anticipated at incident power densities less than 1 mW/cm.[2] Effects have, however, been reported at lower field intensities, such as reversible neurasthenia attributed to field-induced alterations in synaptic transmission and enzymatic activities.[1] Radar technicians repeatedly exposed to presumably low intensity pulsed microwave radiation had flat electroencephalographic records as well as various subjective complaints such as described above.[2]

These reports are characteristic of many reports of relations between occupational microwave or radiofrequency exposure and central nervous system alterations in human beings, all conducted in the USSR, Poland, or Czechoslovakia, and all of which contain limited exposure data. Generally, exposure to pulse-modulated fields seems to result in greater central nervous system change than continuous wave fields of equivalent power density. Lack of exposure data and deficiencies in both statistical methodology and translations from the native language render the interpretation and assessment of central nervous system effects of occupational microwave exposure difficult at best. For this reason, and for the greater experimental control afforded by animal experiments, this latter approach has been widely taken in this and in Communist-bloc nations. These studies have been designed to quantitate relations between microwave and radiofrequency exposure and alterations in neural, central nervous system, and behavioral end-points. The results of such studies may be reviewed to provide indications of consistency with human exposure effects and ultimately lead to a better understanding of the mechanisms of low-intensity microwave and radiofrequency effects on nervous tissue.

Alterations in bioelectrical activity result from exposure of several species to pulse-modulated microwave and radiofrequency fields. Exposure of cats to 147 MHz. VHF radiation modulated at electroencephalographic wave burst frequencies changed specific regional electrical activities and behavior at a time-averaged intensity of 0.8 mW/cm.^{2} [3] High amplitude desynchronization was detected in the electroencephalograms of rabbits exposed two hours daily for three to four months to 2.95 GHz. pulsed fields with 1 μsec. pulse durations at a repetition rate of 1,200 pulses per second at average intensities of 5mW/cm.^{2} [2] A six-week exposure of rabbits to 1 to 10 MHz. RF radiation at 0.5 to 1 KV/m. modulated at 15 Hz. selectively increased the activity of low frequency electroencephalogram components.[4] A 500 Hz. frequency component was induced in the electroencephalograms of rats from long-term exposure to 3GHz., 5mW/cm.^{2} fields pulsed at 500 Hz.[5] The electroencephalogram power spectral density of newly hatched chicks increased significantly in the 14 to 25 Hz. frequency region following a two-hour exposure to 450 MHz. microwaves at a time averaged intensity of 1 mW/cm.^{2} amplitude modulated at 16Hz.[6]

Such studies indicate that the intrinsic rhythmical bioelectrical activity of the mammalian central nervous system may in some cases be perturbed by pulse-modulated electromagnetic fields at induced field gradients as low as 100 mV/cm. and at intensities that result in less than 0.1°C. increase in brain temperature.[7] Although it is not possible directly to relate microwave and radiofrequency-induced electroencephalogram alterations in experimental animals to other types of central nervous system alterations, these results are consistent with experimental results indicating that brain biochemistry,[8,9] physiology,[10] drug tolerance,[11] and behavior[12] are also affected by low-intensity microwave exposure. It may further be concluded that studies of experimental animal responses to low-intensity microwave and radiofrequency exposure are not inconsistent with effects reported from occupational exposure of human beings, although quantitative comparisons are not possible.

Comparison of the effects of microwave and radiofrequency exposure on the hematological and immunological systems of experimental animals and those reported from human occupational exposure also suggest qualitative similarities, although in this case the data base is more limited. Occupational exposure effects include thrombocytopenia, slight decreases in number and spherocytosis and increased acid fragility of erythrocytes, leukocytosis,[13] decreased urinary levels of lactic and pyruvic acids and creatinine, and elevated fasting blood sugar levels.[1] Serum proteins were elevated in 75% of occupationally exposed workers who also had increased serum beta-lipoprotein levels twice as frequently as controls, and serum cholesterol elevations occurred four times more frequently in exposed than control subjects.[1]

Experimental investigations indicate that chronic or long-term exposure to low-intensity microwaves has a differential effect upon blood cells. Such studies in general suggest that pulse-modulated fields induce more pronounced changes than continuous wave fields at the same time-averaged intensity.[14] Where thermogenic microwave stress effects were compared to nonradiation thermal stress, qualitative and quantitative differences in response of the mammalian hematopoietic-reticuloendothelial system have been detected. Microwave exposure effects include transient increases in circulating leukocytes and lymphocytes with less of a suppressive effect upon erythrocytes.[15-17] The mitotic activity and nuclear structure of erythroblasts and bone marrow cells in lymph nodes and spleen of guinea pigs and rats were altered by exposure to 3GHz. fields at an intensity of 3.5 mW/cm.^{2} [16] Rabbits and mice exposed daily for six months to 0.5 and 5 mW/cm.^{2}, 2.95 GHz. fields had increased numbers of lymphoblasts in lymph nodes and increased levels of lymphoblastoid transformations during the first two months of exposure, an effect which persisted for a month following the termination of exposure.[18]

Low-intensity microwave exposure also alters immunological status of experimental animals. A six-week microwave exposure at an intensity of 3 mW/cm.^{2} decreased serum lysozyme activity and mobilization of bone-marrow granulocyte reserve pools.[19] Daily 15-minute exposures of Chinese hamsters for five days to 2.45 GHz. microwaves at power densities of up to 45 mW/cm.^{2} resulted in a transient, dose-dependent change in the rate of lymphoblastoid transformation of unstimulated lymphocytes and a decrease in the frequency of mitogen-stimulated mitoses.[20] Rats exposed 4 to 7 minutes to a 26 MHz. high-intensity radiofrequency field at an intensity of 8.6W/cm.^{2} had a fourfold reduction in the number of circulating lymphocytes and an increase in the number of neutrophils of the same magnitude, maximum responses occurring three hours postexposure, in marked contrast to thermal and sham-exposed controls.[21] The exposure attenuated an induced inflammatory reaction, suggesting an alteration in cell-mediated immunocompentency.[21]

A review of the effects of microwave and radiofrequency exposure of experimental animals and human beings reveals certain consistencies in response, but quantitative comparisons are not possible because of a number of factors, including the limited, or in many cases nonexistent, dosimetric information in the case of human exposures. Although the mechanisms responsible for low-intensity bioeffects are unknown, the data suggest the involvement of nonuniform energy absorption within the bodies of animals or man that may result in microwave-specific thermal gradients and heating rates that depend upon the wavelength and polarization of the field, the orientation, size, shape, and composition of the absorbing body, as well as the presence of reflecting surfaces.[22] Without detailed information on the patterns of internal energy absorption and comparative thermal physiology, it is not feasible to extrapolate data from experimental animals to man.

Another factor limiting the assessment of the biomedical effects of microwave and radiofrequency exposure is the paucity of data on the effects of chronic low-intensity exposure of experimental animals. Most experimental data have been obtained from acute exposures with limited durations of follow-up. Because human exposure is most often chronic or long term, the results of acute experiments are of questionable applicability, and the need is thus established for chronic animal experiments and for well-designed epidemiological studies of occupationally exposed workers.

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GENERAL DISCUSSION: SESSION II*

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W. ROSS ADEY, M.D., WILLIAM M. LEACH, Ph.D.,
DON R. JUSTESEN, Ph.D., STEPHEN F. CLEARY, Ph.D.,
NORMAN SIMON, M.D., RUSSELL L. CARPENTER, Ph.D., AND
RALPH J. SMIALOWICZ, Ph.D.

DR. W. ROSS ADEY: I shall reply to the first question:† Has any attempt been made to produce effects by tapping the skull at critical frequencies?

I know of no work done by tapping the skull, but a great deal of work has been done on whole body vibration. I was involved in this during the early 1960s, when the vibration of man in the course of a space craft launch was a very important consideration in terms of his performance capabilities. The Air Force developed a very large human shaker with a frequency range from about 1 to 30 Hz., and in our studies we used monkeys. There was extremely strong driving of brain wave patterns in the monkey at frequencies between about 11 and 15 Hz. Certain diencephalic and midbrain structures (such as the nucleus centrum medianum) seemed particularly sensitive to that range of frequencies. It is apparently associated with a slight modification of consciousness, but nothing that would be associated with gross deterioration in perceptual or discriminative abilities. Calculations of coherence from cross-spectral analysis between electroencephalographic records and the shaker table indicated that the "driving" in the electroencephalogram did not appear to arise in movements of the brain in the vicinity of the electrodes.

Electroencephalographic activation by stimulation with light and sound has been extensively studied, and light has been universally used to activate the electroencephalogram, along with certain drugs. One can

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†Several written questions were submitted to the speakers by members of the audience.

produce many abnormalities and even epileptic attacks by appropriate frequencies of light stimulation. Auditory stimulation in general is not successful.

I do not think that 10 mW/cm.^{2}, which corresponds to an electric E gradient in air of about 150 V/m., is likely to produce direct, immediate effects on brain function. Indirectly, of course, as pointed out by Dr. Stephen Cleary, 10 mW/cm.^{2} in man at appropriate microwave frequencies may perceptibly increase body temperature. In turn, this would be expected to activate hypothalamic mechanisms controlling brain and body temperature and associated endocrine functions, including steroids. I would expect direct interactions to be of little consequence, but the indirect actions would need to be taken much more seriously.

DR. WILLIAM M. LEACH: The following written question has been submitted: One of the systems that has been used to study the mutagenic effects of ionizing radiation is the *Tradescantia stamen* hair system used by Bond and others at Brookhaven. Has this exquisitely sensitive system been used to test for mutagenic effects of microwaves and other nonionizing radiations? If so, what are the results?

With respect to the use of *Tradescantia* with microwave radiation, no. It was used a number of years ago with infrared radiation and that work was summarized in Swanson's book on cytology and cytogenetics.[1] I do not think that we have an equally sensitive system as far as the sensitivity of the *Tradescantia* system for microwaves at the present time. I do not believe the *Tradescantia* system would be as sensitive with microwave radiation as it is with ionizing, a problem of dosing the beast.

DR. LEONARD R. SOLON (New York City Department of Health): What is your view of the oncogenic potential of microwaves or radiofrequency in the light of chromosomal or genetic influences?

DR. LEACH: I have several answers to that one. I was brought up with three laws of biology, one of which was that which will give it to you will also cure you of it. And, taking that with a little modification, the apparent successes at the present time with microwaves as a moderating influence in the cure of cancer would suggest that microwaves may, indeed, have an influence in the induction of cancer.

The view of microwave radiation as a promoter, I think, is an area of research that has not been exploited, and the statement I just made about the oncogenic potential of microwaves would fall into an area which has not been explored, which is the second law: You have to see it to believe it. We have no explicit evidence that microwave radiation can cause or influence in any direct way the production of cancer.

My third answer: Some cellular studies of microwave radiation indicate that the cells have for some time lost something called "control of mitotic activity." That gets dangerously close to our definition of cancer.

The fourth answer is, I do not know. I understand from very unofficial channels that all involved parties have signed a contract, so we may actually fund a study that will look at this question.

DR. DON JUSTESEN: Dr. Shils has asked my reaction to a paper recently reported in *Science* in which rats exposed to a microwave field at a power density of 1 mW/cm.^{2} showed increased behavioral sensitivity to a tranquilizer.[2]

Let me reiterate what Professors Cleary and Gandhi said today: Power density numbers, even those carefully and precisely obtained in measurements with the best instruments in the best of engineering hands, are highly variable with respect to specific biological thresholds—an observation I shall expand upon in my presentation on behavioral effects of radiofrequency radiation (see pp. 1058-78). To take just one example, that of the grand mal convulsion induced by intense heating of an animal in a radiofrequency field, the power density thresholds cited in the literature range over more than two orders of magnitude, from 3 to more than 300 mW/cm.^{2} Part of this wide range is because a power density number is a time rate. It is, with respect to a field incident on an animal, the rate at which radiofrequency energy flows through a given area of space as it impinges on the animal. With smaller quantities of incident energy per unit of time, more time is needed to deposit enough energy to elevate the animal's body temperature to the convulsive threshold. (For periods less than 15 minutes, the mass normalized quantity of absorbed energy required to convulse an animal is about 25 to 35 j./g. under standard biological and environmental conditions.) Another important factor is the quantity of incident energy that is scattered—not absorbed—by the animal target. All things held equal, a rat in a 2,450 MHz. microwave field will absorb about five times more energy per unit of body mass than will a human being in the same 2,450 MHz. field. In other words, larger organisms absorb less energy per unit of body mass in a microwave field. A third and related factor is resonance. At certain frequencies of radiofrequency radiation and at specific anatomical orientations of an animal in a field, the rate of energy absorption by the entire body or by a part of the body such as the head will increase greatly.

Turning now to the report in *Science,* I note that the senior author, John Thomas of the Naval Medical Research Institute at Bethesda, Md., is an accomplished psychologist whose data on chlordiazepoxide are closely paralleled by other data he will shortly publish[3] on dextroamphetamine. He found that exposure to pulsed 2,450 MHz. microwaves at an average power density of 1 mW/cm^2. can roughly double the effectiveness of a given dose of either drug with respect to its effect on the rat's performance of an operant task.

Dr. Thomas reported provocative data that must, however, be qualified in terms of the factors mentioned above. First, the quantity of energy absorbed by his rats was about 200 μW/g. (whole-body) during 30-minute exposures. Second, because each animal was arrayed in a field in which the head can become electrically resonant, the brains of his animals may have been absorbing radiofrequency energy at the rate of 0.6 to 0.8 mW/g., the thermal product of which is not a trivial addition to the metabolic activity of the brain. Indeed, if dosimetric measurements were to confirm this augmented energy loading of the brain, I would be surprised if modulation of psychoactive compounds by a radiofrequency field did not take place. Finally, the factor of scaling dictates that an adult man in the same 2,450 MHz. field would require a much higher power density to result in equivalent rates of energy absorption per unit of mass.

Dr. Thomas' findings are not of too much concern for human beings so far as 2,450 MHz. energy is concerned, but raise a troublesome question for workers who operate powerful industrial radiofrequency devices at frequencies near those inducing resonant absorption in the human being. Dr. Om Gandhi's data on human models reveal that a worker standing on a conductive floor in a 30 MHz. field will absorb significant quantities of radiofrequency energy per unit of incident energy. Because fields near some industrial devices may effectively average several hundred mW/cm.^{2} one can be legitimately concerned about excessive exposures, especially when the human operator may be taking medication.

Work to continue Dr. Thomas' studies is clearly needed. I would note in passing that his finding of field-induced augmentation of drug efficacy is reminiscent of findings that radiofrequency radiation (albeit at much higher intensities) can also augment the radiosensitivity of neoplasms. Always one to see the constructive side of an issue, I wonder, too, whether field augmentation of drug efficacy would not otherwise prove useful in the clinic. Microwave potentiation of narcotics at lessened dosages, for which there is already strong if indirect evidence,[4] is one possibility.

DR. STEPHEN F. CLEARY: I have been asked at what level of exposure effects become nonreversible. To the best of my knowledge, the only nonreversible effects reported from microwave exposure are cataracts and convulsions or death due to hyperpyrexia. In any case, the dose at which convulsions are encountered is 25 j./g. The cataractogenesis experiments have dose thresholds that in general appear to involve exposures on the order of an hour or so at intensities of about 10 mW/cm.^{2} The rest of the effects reported are generally reversible in the context of the experiments; these have, in general, involved acute or short term exposures. There is a very good possibility that some reversible effects might become nonreversible if the exposures were continued long enough, but this has not been adequately investigated at this point.

DR. NORMAN SIMON: Because this program is on biomedical effects and there has been so much discussion concerning cataracts, I note a possible evasion of the answer to the question the physicians are asked, namely, is microwave radiation cataractogenic for the human being and at what level of exposure or dose?

DR. RUSSELL L. CARPENTER: I think there is no reason to feel that the human species has a species immunity to the effects of microwave radiation. We have very little information concerning thresholds. I would have to say we do not know. However, we can speculate just so long as we do not overspeculate. As I said, from a single acute dose, unless it was an accident in which the subject could not get away, I doubt very much that there would be a cataract. Regarding cases in which there are repeated low dosages (and it would have to be quite low if the subject were to feel no warmth at all), I see no reason why there could not be a cataract as a result.

But when you look at the human histories, they are so incomplete. For example, an ophthalmologist sees a patient with a posterior subcapsular cataract. The fact that that patient may at some time have been exposed to microwave radiation does not, of itself, automatically constitute a cause-and-effect relation. But too often this assumption has been made. Suppose we see someone who develops a posterior subcapsular cataract; we cannot extrapolate right from the rabbit to the man. They react differently at different frequencies. If we get a patient with a posterior subcapsular cataract and investigate his history, it is very difficult to reconstruct retrospectively the conditions of any microwave exposure. At the most it can be said that he was near some microwaves. How much? We do not know. How often? Don't know. How long a period of exposure? Well, that happened some while ago. The problem is an extremely difficult one.

There have been a number of cases reported in literature for human cataractogenesis from microwaves. Most of them have been reported by Dr. Zaret, who feels that the pathognomic character is a thickening of the posterior capsule, but he says that that is not an actual thickening but one that seems to be a thickening when you view it with a slit lamp. I have been collecting lenses from cases of alleged microwave cataract in humans. I have serially sectioned them. I am trying to find out whether the radiation cataract, the so-called "microwave cataract," has any unique characteristic or characteristics like another known type of cataract. The only thing I have yet been able to find is two cases which bear some of the characteristics of the ionizing radiation cataract, except that they developed more rapidly.

I have a case well documented in which we were able to reconstruct the conditions of exposure. It was a case of microwave diathermy applied because of strained neck muscles. The subject subsequently developed bilateral posterior subcapsular cataracts. We could eliminate any other possible etiology. There was no familial history. He had taken no corticosteroids. There had been no uveitis or diabetes. So you could say, "Aha, now there is a case of microwave cataract." But what do you do with the cases of idiopathic cataract? You cannot just ignore them. Fortunately, we were able to photograph the lenses. We obtained them after extraction. I have serially sectioned and studied them and they show balloon cells migrating under the posterior capsule. There appears to be no thickening of the posterior capsule. The microwave power density that we could measure, next to his right eye, was 22 $mW/cm.^2$ and at his left eye, which developed a posterior subcapsular cataract, it was only 8 mW. I am puzzled by that case and I think perhaps I may be too rigorous. But I think we should be rigorous because if we are going to report cases of microwave cataract just because of a possible association with a microwave oven, that is not scientific. I know of one case where an ophthalmologist diagnosed microwave cataracts in a woman who owned a microwave oven. The fact was that she did not use the oven. Her husband, who is a radiologist, gave it to her and she would not use it. He used it, but he did not have the cataracts.

I think we shall have to say that so far as the human being is concerned, we do not have sufficient knowledge.

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REVIEW OF SOVIET/EASTERN EUROPEAN RESEARCH ON HEALTH ASPECTS OF MICROWAVE RADIATION*

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THIS paper will discuss the health aspects of microwave radiation in the Soviet Union and other Eastern European countries and, in some cases, will compare their approaches and views to those in the United States and Western countries. Most of the discussion will deal with research, reported human effects, and allowable safe levels of exposure in the Soviet Union because I am more familiar with the situation in the Soviet Union than in other Eastern European countries. I shall also report on the increased interchange and interaction between Soviet and Eastern European scientists and American scientists over the past seven years. This discussion will include a review of the U.S.-U.S.S.R. cooperative program on the biological effects of microwave radiation.

It would be convenient to talk about the Soviet research as if it were composed of a single approach. Generalities can be found in some features of their microwave research program, but their research methodology is as varied as those in the United States. The particular approach to a problem depends on the investigator, the institute performing the research, or both. I shall present some general statements to describe Soviet and Eastern European thinking concerning the health aspects of microwave radiation. It must be realized that these are my impressions and understandings after six visits to the Soviet Union, and that such a presentation oversimplifies a complex subject.

WESTERN AND EASTERN SCIENTIFIC EXCHANGE

For many years literature from the Soviet Union and other Eastern

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European countries have reported biological effects of microwave radiation on humans and animals at low levels of exposure (less than 10 mW/cm.^{2}). Although effects on almost all biological systems were reported, most changes dealt with alterations in the nervous system and behavior. Unfortunately, the Soviet literature in general does not provide details of experimental design and research methodology. The normal research paper usually includes the frequency of exposure (sometimes not the exact frequency, but only the designation "microwave" or a frequency band in the microwave region), the incident-power density of the radiation, the duration of exposure, and animal species. Very little, if any, information is given on how the animals are exposed, field characteristics, energy absorption, how control animals are maintained, and other important experimental design matters required for meaningful research. In most cases the bulk of the paper presents many biological changes with little description of the techniques used to measure the observed alterations. Where effects on humans are reported, exposure frequency is usually designated in such broad terms as microwaves, sometimes the range of levels measured within the general area, and sometimes the length of time the person has worked in the area are given. Little or no discussion of how the exposed and control groups are constituted and the possible presence of other environmental factors, both chemical and physical, is provided. Most reported results are subjective, and techniques used to obtain the results are often not given.

In spite of these difficulties with Soviet and Eastern European research, this large volume of data has been an important driving force in the United States in producing concern over the biological effects of microwave radiation and in generating research to evaluate the significance of microwave exposure. Attempts to duplicate some of the Soviet and Eastern European work by Western investigators have not obtained, in most cases, the same biological changes, but because of the lack of information in the Soviet and Eastern European literature, it is technically impossible to duplicate their research in all aspects. Attempts were usually concluded by a statement which read something similar to this: attempts to duplicate the results obtained by the Soviet or Eastern European investigators were unsuccessful, but, because of lack of information in their reports, we were unable to duplicate all aspects of their experiments.

An almost total lack of scientific interchange and cooperation with Soviet and Eastern European investigators before 1972 made the dilemma seem insurmountable, and most American scientists considered the large volume of Soviet and Eastern European literature of little significance in evaluating the hazardous effects of microwave radiation. In 1971 the United States and the Soviet Union agreed to cooperate in health-related research areas. In March 1972 an agreement was signed between the U.S. Department of Health, Education and Welfare and the U.S.S.R. Minstry of Health to cooperate in the area of cancer, heart and lung disease, and environmental health. The directors of the National Cancer Institute, National Institute of Heart and Lung Diseases, and the National Institute of Environmental Health Sciences were appointed to work with Soviet counterparts to develop cooperative plans for research in each of the specified areas. In January 1973 a Program of U.S.-U.S.S.R. Cooperation on the Problem of Environmental Health Research was signed. This original program did not include microwave bioeffects, although the United States at this time emphasized its interest in including microwave bioeffects in the program.

At a meeting in March 1974 it was agreed to include microwaves in the cooperation using the following steps:

1. Exchange of national literature surveys on the biological effects of nonionizing (microwave) radiation
2. Two to four specialists to be exchanged before the end of 1974 to familiarize themselves with current research in each country
3. Possible cooperative research to be discussed in December 1974 during a Symposium in Moscow

Concise surveys of national literature were exchanged and the Soviet Union reviewed only research during 1970-1972. They emphasized general population exposure and did not include significant research from the occupational institutes. In May 1974 five scientists from the United States traveled to the Soviet Union and visited both the General and Muncipal Hygiene Institute in Kiev and the Industrial Hygiene and Occupational Diseases Institute in Moscow. These two Institutes are responsible for occupational and general population microwave-exposure standards in the Soviet Union. During this time scientific papers were presented on research being performed in both the United States and the Soviet Union. In February 1975 three Soviet scientists visited the United States, and in September 1975 a meeting was held in Kiev to develop a cooperative program. The formal agreement to cooperate in the area of the biological effects of microwave radiation was signed in October 1975. Since 1975 there have been yearly exchange visits by scientists from both countries.

Other important contacts with Soviet and Eastern European countries took place at the time the cooperation was being developed. On October 15-18, 1973 an International Symposium on the Biological Effects and Health Hazards of Microwave Radiation was held in Warsaw, and provided important contact with researchers from the Soviet Union and other Eastern European countries. Scientists from the Soviet Union, Poland, Czechoslavakia, and the German Democratic Republic participated, and symposium proceedings provide an initial reference from which to discuss Soviet and Eastern European research.[1]

Since 1973 the contacts with Soviet and Eastern European investigators have increased. Exchange visits to laboratories have become more numerous, and participation by Soviet and Eastern European scientists in international symposia have increased during the past five years. Literature and scientific information not previously available have been exchanged and some of this more recent research is discussed in this paper.

Soviet Research

I visited institutes concerned with general and communal hygiene and with industrial hygiene and occupational diseases. These institutes have responsibilities similar to those of the Environmental Protection Agency (EPA) and National Institute for Occupational Safety and Health (NIOSH). They have the responsibility for health-effects research and for developing safety standards. The Soviet Academy of Science Institutes perform more basic, sophisticated research on many of the same problems under investigation by the Ministry of Health Institutes. Relevant information is used by the Ministry of Health to develop standards. In general, the Academy of Science Institutes are much better equipped than the Ministry of Health Institutes and the Academy of Medical Science Institutes, and supposedly have the best scientists. I did not always find this to be the case.

Most institutes of occupational hygiene and industrial diseases have clinics where those who work under conditions suspected to be hazardous are examined periodically to determine if harmful effects are occurring. This explains to some degree the large amount of human bioeffects data reported by the Soviets which are not in most cases from epidemiological studies with experimental and control groups as closely matched as possible, but from examinations in these clinics. The possibility exists that other factors in the workplace could produce the effects reported. This also explains to some extent the interest the Soviets have in combinations of microwave, ionizing radiation, and noise in animal experiments.

The laboratories carrying on research into the biological effects of microwaves I visited all noticeably lacked engineering and physicist support, but appeared capable in the biological sciences. This lack of engineering support and knowledge about microwave radiation is evident from their exposure, measurement, and instrumentation capabilities. I shall discuss two examples of microwave exposure observed during a visit to the Soviet Union in 1974.

The first arrangement was observed in one of the general and communal hygiene institutes. The exposure room had no absorber on the walls to prevent reflections from objects in the room and walls. The microwave source was a standard diathermy unit radiating at a frequency of 2,375 MHz. Pregnant rats (10 to 15 in number) were all exposed in a wooden box with a plexiglass front with food and water containers. The power density was measured using a PO-1 Soviet instrument which consists of a receiving horn, thermistor, and power flux meter. The PO-1 instrument is the standard instrument for measuring power densities in the microwave frequency range. Control animals were placed in the same room in a similar box behind the exposed animals. The exposure usually ranged from 0 to 100 μW/cm.^{2} No specific absorption rates were measured in any of the experiments which we observed because they say they are exposing at low levels where no heating of tissues occurs.

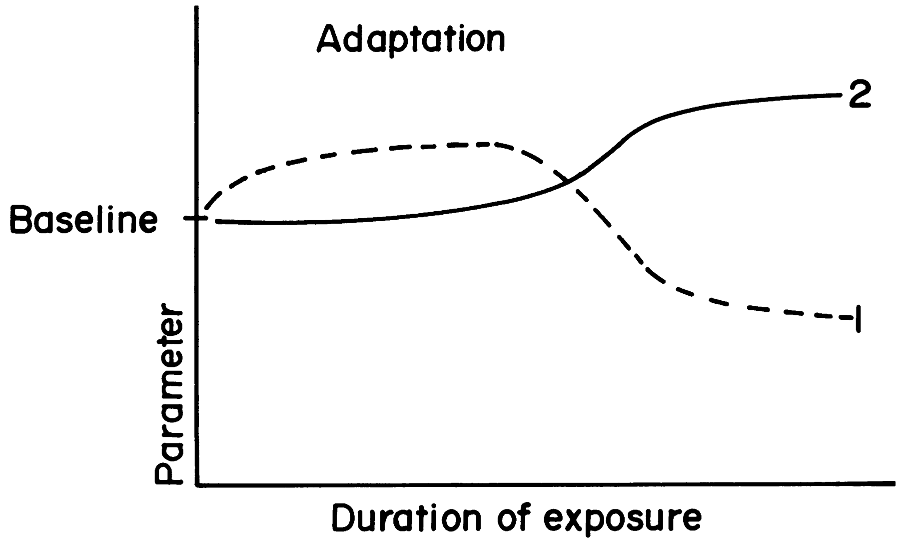
A second exposure room was in an occupational hygiene and industrial diseases institute in Moscow from which a large volume of literature has been published and from which the occupational exposure standard of 10 μW/cm^2 was generated. A standard gain horn was used as the irradiator. We were told that no measurements were made of the fields at the specimen location because the specimens were far enough from the horn to be in the far field. They determined their exposure intensity by calculating the values using free field equations in the far field of a radiator. The walls of the room were not covered with microwave absorber but absorber was located behind the exposed animals. The animals were separated in plexiglass boxes but were not spaced far enough apart to prevent scattered irradiation from one animal from impinging upon adjacent animals. In this experiment, control animals were neither located in the same room nor handled the same way as the experimental animals. Again, no energy-absorption measurements were made, although exposures were in the low milliwatt/square centimeter range because they considered these levels to be nonthermalizing.

Contrary to the lack of engineering and physical scientific expertise associated with their microwave research, the biologists appeared capable of performing the required research. The major constraint in their biological capability seems not to be due to the quality of scientists but to the lack of up-to-date analytical equipment and instrumentation. Many of their laboratories are very limited in the amount of equipment, and much of what they have is obviously very old.

Recent visits to the Soviet Union have shown significant improvement in their exposure systems. Much of the improvement is probably due to recent visits to the United States and to observation of exposure systems in this country. The two institutes discussed above now have exposure rooms with absorbers on all walls and, in some cases, where multiple animals are being exposed, the exposure is from above. They also realize that much of their earlier electroencephalographic data, taken with metal implanted electrodes, are not valid because of potential artifacts produced by the interaction of the electrodes with the microwave fields.

During visits to the Soviet Union, some insight into the approach of the Soviet health institutes to studying this problem has been obtained. They believe that the more complex the biological system the greater the possibility of it being affected at low levels of exposure. Therefore, the health institutes in most cases use whole animal systems in their studies. They believe it is more important to obtain effects on different species of animals to extrapolate results from animal to man rather than to use *in vitro* or more simple systems to obtain basic mechanism of interaction data to enable such an extrapolation.

Adaptation is also an important consideration in their research. They state that human beings evolved under certain environmental conditions. Changes in these environmental conditions, increase or decrease, affect human beings, but human beings have adaptive capabilities which enables them to adapt to certain levels of changes without harmful effects. Levels greater in magnitude than those adaptive levels are defined as hazardous. Some of their research reports a biphasic change in a given biological parameter with increasing exposure time (see figure), which they explain by suggesting that the animal is attempting to adapt to microwave stress and overcompensates to the point that the change reverses direction (curve



Two suggested adaptation processes in response to microwave exposure.

1). Another form of adaptation which they discuss involves the idea that in the initial stages of exposure, animals can compensate for the microwave stress without changes in biological indicators. After a period of time, the animals can no longer adapt, and biological changes are then observed (curve 2).

Most Soviet research is performed, therefore, at low levels of exposure for long exposure duration. They consider that power densities above 1 $mW/cm.^2$ are high enough to produce harmful effects, and see no reason to perform research above this level. When we respond that in some of our experiments we see no significant changes at exposure levels above 1 mW/cm., their answer is that we did not expose long enough. Most of their low level experiments are for six months to a year, while American experiments are usually in terms of a few weeks. Long-term experiments using low levels of microwaves must be performed in the United States before the Soviet results can be verified or refuted.

Some Reported Biological Effects

Before reporting on Soviet and other Eastern European biological effects, the results of the U.S.-U.S.S.R. cooperative program should be briefly reviewed. In the early stages of the cooperative program, it consisted mainly of an exchange of results on projects related to the central nervous system and behavior. American research consisted primarily of acute experiments with exposure levels generally of 5 mW/cm.^{2} and above, while Soviet experiments were long-term, low-level experiments at 500 μW/cm.^{2} and below. At the end of the first year of the cooperation, the Soviets reported changes in bioelectric brain activity at 10, 50, and 500 μW/cm.^{2} in rats and rabbits exposed for 7 hours/day for 30 days to 2,375 MHz. radiation. Levels of 10 and 50 μW/cm.^{2} stimulated brain activity, while 500 μW/cm.^{2} suppressed activity as seen from an increase of slow, high amplitude Δ-wave in rabbits. At 500 μW/cm.^{2} a decrease in capacity for work, in investigative activity, and sensitivity to electric shock threshold in rats were reported. Research by American investigators on rats exposed to 5 mW/cm.^{2} for shorter durations of exposure to 2,450 MHz. radiation showed no statistical difference in electroencephalogram, no change in locomotive activity in a residential maze, and no change in performance on a fixed ratio schedule of reinforcement below 5 mW/cm.^{2} (0.5 and 1.0 mW/cm.^{2}) but a trend toward decrease in performance at 5 mW/cm.^{2} and a large decrease in performance at 10 and 20 mW/cm.^{2}

It became obvious that, except for our being more familiar with their experimental design, we were no closer to understanding differences between American and Soviet results. It was then decided to perform a duplicate experiment to determine whether similar effects could be observed. Rats were exposed from above for seven hours/day, seven days/week for three months to 500 μW/cm.^{2}. Dr. Richard Lovely of the University of Washington, project leader on the duplicate project, spent four weeks in the Soviet Union to observe the behavioral and biochemical tests performed on the animals. The American study found a drop in sulfhydryl activity and blood cholinesterase as reported in the Soviet study. Blood chemical analyses at the termination of three months exposure indicated that exposed animals, relative to controls, suffered from aldosteronism. The latter interpretation of the high sodium-low potassium levels found in the blood was confirmed by necropsy and histopathologic study of the adrenal glands, revealing that the zona glomerulosa was vacuolated and hypertrophied. In addition, *all* behavioral parameters assessed at the end of three-month exposures revealed significant differences between groups in the same direction as those reported in the Soviet study, i.e., increased threshold to footshock detection, decreased activity in an

TABLE I. FREQUENCY OF HYPOTONIA IN PERSONNEL EXPOSED TO MICROWAVES ACCORDING TO SOVIET AUTHORS

Author and year	*No. of individuals examined*	*Frequency of hypotonia %*
Kerovski, A.A., 1948	87	38
Osipov, Ju A., 1952	108	30
Shipkova, V.A., 1959	110	20
Orlova, A.A., 1960	525	26-33, various groups
Uspenskaja, I.V., 1961	100	30
Volfavskaja, R.N. et al., 1961	101	27-45, various groups
Frelova, L.T., 1963	172	25.6
Komarov, F.I. et al., 1963	53	22.6
Gembricki, E.V., 1966	210	14

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open field, and poorer retention of an avoidance response when reassessed following conditioning. This replication of the Soviet results at 500 μW/cm.^{2} emphasizes the need for additional long-term, low-level microwave bioeffects research.

Effects on human beings. Most of the bioeffects research in Eastern European countries is performed by Soviet and Polish investigators. A small amount of data, mainly effects on human workers, have been reported by Czechoslovakian scientists. Reported effects on personnel occupationally exposed to microwaves has been summarized by Baranski and Czerski[2] and are shown in Tables I and II. These results come primarily from two groups in the Soviet Union who have done extensive clinical studies on microwave workers. Baranski and Czerski[2] refer to the groups as the Moscow group and the Leningrad group. The Moscow group has reported changes in white blood cells, although no characteristic changes in peripheral blood have been found. Blood proteins, serum histamine content, and enzyme activity have been reported but they returned to normal levels after a few days of rest. The influence of microwaves on the autonomic nervous system was evidenced by reports of vagotonia, bradycardia, and hypotonia. With periodic exposure to power density levels of 0.1 to 10 mW/cm.^{2}, marked changes in cardiac rhythm (variability or pronounced bradycardia) were reported. Hypotonia was one of the more pronounced effects (Table I). Prolonged exposure to power density levels from 0.01 to 0.1 mW/cm.^{2} produced effects similar to those

TABLE II. COMPLAINTS OF MICROWAVE WORKERS (%) ACCORDING TO VARIOUS AUTHORS

Author and year	*Headaches*	*Fatigue dispro-portional to effort*	*Sleep distur-bances*	*Irritability*	*Abnormal sweating*	*No. of workers examined*
Uspenskaja, N.V., 2963	37	31	29	9	7	100
Sadtchikova, M.N., 1963 (various groups)	12-39	20-35	—	8-27	—	447
Kilmkova-Deutschova, 1963 (Czech.)	43	39	35	—	—	73
Serel, 1959 (U.S.S.R.)	43	4	45	10	—	103
Tjagin, N.V., 1966 (U.S.S.R.)	33.5	46.2	25.3	9.6	25.5	573
Ramzen-Evdokimov and Sorokin, 1970 (U.S.S.R.)	44	29	35	36	25	155
Controls						
Uspenskaja, 1963	15	22	2	10	—	100
Sadtchikova, 1963	8	10	—	8	—	100
Tjagin, 1966	10.8	5.9	8.7	—	2.7	184
Ramzen-Evdokimov and Sorokin, 1970	7	8	3	—	4	50

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mentioned above. The symptoms were less pronounced and reversible after periods of rest.

The Moscow group also reports that chronic exposure leads to a neurocirculatory syndrome in three stages. The first symptoms are reversible and include changes in blood pressure and cardiac rhythm. In the second stage, cardiovascular changes become more pronounced, and electroencephalographic changes which indicate disturbance of the diencephalan were also found. Hyperactivity of the thyroid is also indicated. A condition defined in Soviet literature as an "asthenic state" may develop. Such subjective complaints as headaches, excitability and irritability, fatigue, and pains around the cardiac region (Table II) characterize this stage. The third stage of effects is characterized by a greater magnitude of change in the complaints and symptoms and additional electroencephalographic changes.

The Leningrad group discusses their findings in terms of an acute microwave syndrome and a chronic microwave syndrome. The acute syndrome is characterized by subjective complaints of headaches, nausea, vertigo, and sleep disturbance. Hypertonia, changes in cardiac rhythm, skin rash, and decrease in amplitude of electroencephalographic alpha waves are also characteristic. Symptoms are transient and disappear completely after rest. The chronic syndrome is expressed in terms of adaptive processes. Subjective complaints of headaches, fatigue, and the like occur during the first three months of exposure, and reappear about the sixth to eighth month. After the first year a period of adaptation occurs which varies in duration. The complaints and symptoms of neurovegetative disturbances reappear after five years of work (chronic overexposure syndrome). This chronic overexposure syndrome is characterized by complaints of headaches, irritability, sleep disturbances, weakness, decrease of sexual activity, pains in the chest, and a general unhealthy feeling ("a general feeling of ill-being").

A large number of Polish clinical studies confirm the Soviet findings on the periodicity of the subjective complaints for exposures to 1 to 10 mW/cm.^{2}.[2] Subjective complaints were exactly the same as described by the Soviet authors (Table II), and were observed in up to 70% of persons exposed to the 1 to 10 mW/cm.^{2} power density levels. The few Czechoslovakian reports (Klimkova-Deutschova[1] and Serel[2]) agree with the Soviet authors (Table II). They also discuss symptoms in terms of a "neurasthenic syndrome."

TABLE III. SOME DATA ON THE EXPOSURE OF MAN AND ANIMALS TO MICROWAVE FREQUENCY FIELDS (ARRANGED ON INTENSITY SCALE)

Power density		
W/cm.²	1	Eye cataracts in dogs after exposure for three to five hours
	800	
	600	(L,M) Pain sensation during exposure
	300	Brief increase in blood pressure; after 20 to 60 minutes marked decrease (cat, rabbit, dog)
	200	(L) Malformation of offspring after exposure for 10 to 15 minutes (chicken eggs, $\lambda = 12.6$ cm), death of cats and rabbits ($t = 20$ to 60 minutes). Reduction of redox in tissue
mW/cm.²		
	100	(M) Increase in blood pressure with subsequent marked decrease; in case of chronic exposure—stable hypoxia. Stable morphologic changes in the cardiovascular system. Bilateral cataracts.
	40	(L) Increase in blood pressure with subsequent marked decrease; multiple hemorrhages, $\lambda = 3$ to 10 cm, in liver (dilatation of vessels and hemorrhages $\lambda = 10$ cm.). Increase in blood pressure of 20 to 30 mm. Hg (exposure for 0.5 to 1.0 hour).
	10	(M) Changes in conditioned reflex activity, morphological changes in cerebral cortex (L). Vague shifts in blood pressure (exposure time 150 hours), change in blood coagulability. Hyperplasia of liver cells, $\lambda = 3$ to 10 cm. (chronic exposure). ECG changes (wavelengths other than DTsV—expansion not given). Change in receptor apparatus.
	5	Threshold intensity at which there are changes in the testis and blood pressure changes (multiple exposure). Brief leukopenia and erythropenia. Darkening of the crystalline lens.
	3	(M) Decrease in blood pressure, tendency to quickening of pulse, fluctuation of cardiac blood volume.
mW/cm.²		
	1	(M) Decrease in blood pressure, tendency to quickening of pulse, insignificant variations in cardiac blood volume. Decrease in blood pressure level, decrease in ophthalmotone (t: daily, 3.5 months). Disadaptation, disorders of immunological protection control mechanisms (L).
	400	Depression of secretions in dogs
	300	(L,M) Some changes in the nervous system in case of exposure for 5 to 10 years
	200	Changes in function of neurons in dogs
	100	(L) Tendency to decrease in blood pressure with chronic exposure
	40	(L) Tendency to decrease in blood pressure with chronic exposure
μW/cm.²		
	20	(M) Thinning of pulse, tendency to a decrease in arterial pressure. Cases of body sensitivity observed. Well-expressed increase in skin temperature in persons earlier exposed.
	M	Data applies to man—all other to animals
	L	Lowest power density indicated by authors

Source: Minin, B.A.: *Microwaves and Human Safety*. U.S. Joint Publication Service, JPRS 65506. August 20, 1975.

TABLE IV. SOME RESULTS OF EXPERIMENTAL STUDIES ON THE BIOLOGICAL EFFECTS OF VERY LOW INTENSITY MICROWAVES (UP TO 150 μW/cm.^{2})

Investigated function	*Radiation intensity $\mu W/cm.^2$*	*Character of changes*	*Investigator*
Body weight	150	Lag in weight (chronic experiment)	V.V. Markov
Arterial pressure	150	Biphasic course with marked hypotension (chronic experiment)	V.V. Markov
Reproductive function	150	Decreased fertility, decreased litter size, increased number of defective progeny, increased embryonic mortality etc. (chronic experiment)	A.N. Bereznitskaya et al.
Central nervous system	10-20 and higher 150 150	1. EEG changes with predominant synchronization (acute experiment) 2. Bivariant shifts with predominance of activation (acute experiment) 3. Bivariant shifts in the subcortical-basal structures (chronic experiment)	Z.V. Gvozdikcova et al.
Electromyography	150	Increased electrical activity of active unit	V.V. Markov
Hypothalamus-drenal cortex System	150	1. Weight change of endocrine glands (hypothysis adrenals) 2. Change in the neurosecretory function of the hypothalamus. 3. Tendency for increased levels of norepinephrine in the adrenals	N.K. Demokidova
Metabolism	150	Changes in water and electrolyte metabolism (Na, K, water, and total nitrogen excretion)	N.K. Demokidova
Immunology	150	Inhibition of neutrophils phagocytic activity	A.P. Vokova and V.V. Markov

Source: Gordon, Z.V., editor: *Biological Effects of Radiofrequency Electromagnetic Fields*. U.S. Joint Publication Service, JPRS 65506, August 20, 1975.

TABLE V. RADIOFREQUENCY STANDARDS FOR OCCUPATIONAL EXPOSURE TO CONTINUOUS WAVE FIELDS (WORKING DAY)

Country	*Radiation frequency (GHz.)*	*RFR intensity (mW/cm.²)*
United States		
ANSI*	0.01-100 GHz.	10
OSHA†	0.01-100 GHz.	10
ACGIH‡	0.1 -100 GHz.	10
Great Britain	0.3 - 30 GHz.	10
Canada	0.1 -100 GHz.	10 (1 proposed)
Sweden	0.3 - 3 GHz.	1
Poland	0.03-300 GHz.	0.2
Czechoslovakia	0.3 -300 GHz.	0.025
U.S.S.R.	0.3 -300 GHz.	0.01

*American National Standards Institute
†Occupational Safety and Health Administration
‡American Congress of Governmental Industrial Hygienists
Note: Some countries have more permissive intensities for shorter exposure times and more restrictive intensities for exposure of the general population.

Effects on animals. A compilation of many Soviet reports on the effects of microwave radiation on animals is presented (Tables III and IV). Both Soviet and Polish investigators report behavioral, central nervous system, cardiovascular system, biochemical, endocrine and metabolic, hematological and reproductive functional changes in animals. All of these reported effects (Tables III and IV) were observed at power densities equal to or less than 10 mW/cm.^{2} and many of the effects were observed at power densities less than 1.0 mW/cm.^{2} Biological changes in both human beings and animals have been reported below 500 μW/cm.^{2}

MICROWAVE EXPOSURE STANDARDS

The current standards for occupational exposure to continuous wave fields for a working day show large differences between Soviet and other Eastern European countries and western countries (Table V). Although Gordon[3] also presents a permissible exposure level of 1 μW/cm.^{2} for the general population as well as the 10 μW/cm.^{2} for occupational exposure, the Soviet Union does not have at this time a "legal" permissible general population exposure levels. However, the Institute of General and Communal Hygiene in Kiev, under the direction of the Soviet Ministry of Health, has proposed a general population standard for microwave exposure of 5 μW/cm.^{2} (Table VI). This maximum permissible level is enforced at present and will become an official standard at the end of this

TABLE VI. MAXIMUM ALLOWABLE LEVELS (MAL) OF ELECTROMAGNETIC ENERGY IN THE HUMAN SETTLEMENTS

Radiowaves ranges	*Limits of ranges (frequency, wavelength)*	*MAL of EMW energy on the dwelling territory*
Long waves	30-300 kHz. (10-1 km.)	20 V/m.
Middle waves	0.3-3 MHz. (1-0.1 km.)	10V/m.
Short waves	3-30 MHz. (100-10 m.)	4 V/m.
Ultrashort waves	30-300 MHz. (10-1 m.)	2 V/m.
Microwaves 24-hour exposure	300 MHz.-300 GHz. (1 m.-1 mm.)	5 μW/cm.^{2}

year unless reasons not to accept it are presented to the Ministry of Health.

Differences in the meaning of standards exist between the Soviet and other Eastern European countries and the United States. First, the maximum permissible exposure level is set at the value where no biological effects occur. No differentiation between effects and hazards is made in setting their standards. Although most of their reported effects at low levels are reversible and return to normal levels after a period of time, and although they recognize that a difference between an effect and a hazard might exist, these facts are not considered in setting maximum permissible levels. Second, the occupational and general population standards in the Soviet Union and other Eastern European countries are not applicable to persons in military and space programs. This enables them to avoid the problems of restrictive use in high priority applications when setting very stringent maximum permissible exposure levels for lower priority situations. This exclusion of individuals in certain work activities is of course impossible in the United States if harmful effects do in fact occur at a given level and duration of exposure. Unfortunately, with the data base that exists today, this "safe" level cannot be set with certainty for either the general population or occupational groups.

SUMMARY

The Soviet and other Eastern European countries have published much information on the biological effects of microwave radiation. Almost no contact between Eastern European and Western scientists on this problem existed prior to 1972, when the cooperative agreement on environmental health was signed with the Soviet Union. Since 1972 scientific exchanges have occurred on an annual basis with some American scientists staying as long as six weeks to observe Soviet research. Other exchange programs between Polish investigators and American agencies have taken place over the past several years. The exchanges have provided us with a better insight into research in these countries.

Because of my direct involvement with the U.S.-U.S.S.R. cooperative program, this paper has concentrated on Soviet research. These institutes stress human clinical studies and long-term, low-level effects on whole animal systems. They report an "asthenic syndrome" in occupationally exposed workers, characterized by headaches, irritability, fatigue, sleep disturbances, pains in the chest, and a general feeling of ill-being. Polish and Czechoslovakian investigators report the same human effects as the Soviet investigators. Reports of animal studies by Soviet and Polish investigators at exposure power densities of 10 $mW/cm.^2$ and below include effects on central nervous system, behavior, cardiovascular system, hematology and blood biochemistry, immunology, endocrinology and metabolism, and reproductive function.

Maximum permissible exposure levels in the Soviet Union and other Eastern European countries and accepted safe levels in the United States differ drastically. For a full working day of exposure, the Soviet standard is 1,000 times less than that presently accepted in the United States. However, the Soviet level is set where supposedly no biological changes occur, even if reversible. No evaluation of the biological changes in terms of harmful consequences is incorporated into the standard. It should also be noted that certain programs (military and space) do not adhere to the same requirements as those set by the Soviet Ministry of Health.

Questions and Answers

DR. RUSSELL CARPENTER: Dr. McRee, were methods of measuring the microwave levels of power what you showed us, how can we really take any stock in what they offer? When they say "low levels" and one measures it with plaster walls and no anechoic chambers, I do not know what their device was. Do you think their measurements are very reliable?

DR. MCREE: The PO-1 meter that they used is a reliable device for measuring incident power density. If they were exposing the animal at 1 or 10 $mW/cm.^2$ and one had a 10 to 100 amplification factor or error factor in the measurement, obviously it could be a high level thermal effect. But they report biological changes at 10 μW/cm.^{2} and I just cannot see that much error. I would estimate a factor of 10 in that particular exposure. Dr. William Guy and I had some meters over there but we, unfortunately, were not allowed to take some measurements that we wanted, but one can look at the reflectivity and so forth at 10 μW incident and see no greater increase than about 100 μW to 1 mW. They do not report specific absorption rates. In fact, I have never seen them measure or attempt to measure these. Because they say that at their levels they have no heating. I could not measure a specific absorption rate at 10 μW/cm.^{2} So they don't really feel there is a need. They have improved their exposure systems. The plaster walled room shown in the slide with the animal in front of the diathermy unit has now been replaced by a standard gain horn irradiator, animals in the far field, and microwave absorbers on the walls. We have done a duplicate project with them. At exposure to 500 μW/cm.^{2} for seven hours per day, seven days a week, for three months, we examined blood chemical and behavioral changes. Behavioral changes measured were almost identical to those measured by Shandala's group. This work at the University of Washington by Dr. Lovely, I think, amplifies the problem, or rather the realities, of the situation. We must do some chronic low level work, and we might be surprised. I think that Lovely and Guy were probably more surprised than anyone else that they found those results at a half mW/cm.^{2}

MR. EDWARD L. HUNT (Walter Reed Army Institute of Research): The Russians have begun to adopt some of the same essential kinds of specifications that we use. For example, Tyazhelov in Helsinki has used watts per kilogram, which is our specific absorption rate (SAR).

DR. MCREE: They have begun to do this, particularly where it is relevant, where they think they can measure specific absorption rates. Of course, one can measure such rates in any condition if one just exposes at a higher power density level and extrapolates down to the low level at which one tries to do the experiment. But one encounters heat transfer conduction problems because one is basically measuring the temperature.

MR. GEORGE WILKENING: Is it a valid argument not to use SAR because of heat? One doesn't necessarily have to have it, does one?

DR. MCREE: One must measure the fields or the temperature and unless the BRH field probe is as good as they say, and is made available....

DR. JAMES FRAZER: Dr. McRee, you are only halfway to the solution.

When you measure SAR, you indeed measure the electric field in the tissues.

DR. MCREE: I agree, but presently most people obtain SAR from temperature measurements. Most people do not have a field probe with which to measure local fields. Most do have a temperature measuring device.

DR. DON R. JUSTESEN: Does this not imply that human beings are more sensitive to weak electromagnetic fields than the best sensors that the engineers can devise? Presumably, it is beyond the capability of the engineers to detect these fields, while the human being not only reacts to them but suffers terribly from all manner of neurasthenic illness. Is this not the implication?

DR. MCREE: You are trying to make a point. What is it?

DR. JUSTESEN: It is possible that the central nervous system is the most sensitive of all instruments to weak radiofrequency fields—that we could throw away our power-density meters and more accurately index the presence of extremely weak but nonetheless harmful fields simply by counting the number of factory workers or embassy employees with neurasthenic symptoms.

MR. WILKENING: To use the incidence of a malady in which the role of microwaves is at best conjectural as an index of field strength would certainly beg the causal question.

DR. JUSTESEN: Precisely my point. I spoke with tongue in cheek. Although I do not disparage the sensitivity of the nervous system to electromagnetic fields, I do disparage the tendency of some individuals to blame any manifestation of disease on the microwaves. A good case in point is Dr. Milton Zaret's assertion[5] that over-the-horizon radar beams from the Soviet Union are responsible for the high incidence of cardiac disease and heart failure in the North Karelia district of Finland.[1] There is little doubt that the Soviet-launched radiation incident on the inhabitants of this district is unmeasureably small—much less than the microwave radiation emitted by the human body. One must disparage the assertion of an etiological role of any agent in any pathological condition in the absence of measurement, correlation, and verification.

DR. MCREE: I understand the point Dr. Justesen makes, and it is a valid one. We should not jump to the conclusion that health effects found in persons who might be in a location where microwaves are present are due to the microwave radiation. It is important to characterize the microwave radiation levels and any other environmental factors which might be present. However, the Soviets can measure accurately microwave levels in the low μW/cm.^{2} range and have conducted long-term experiments on animals at these levels. Reversible biological changes have been reported in these experiments at power density levels as low as 5μW/cm.^{2}

DR. JUSTESEN: Dr. Zorach Glaser, formerly with the Department of the Navy, and now in transition from the National Institute of Occupational Safety and Health to the FDA's Bureau of Radiological Health, is owed a debt of gratitude by all physicians, biologists, and biological engineers who labor in the radiofrequency field. For years Dr. Glaser has performed the nearly thankless task of cataloging, updating, and disseminating titles and sources of published information on biological effects of radiofrequency fields. His current compendium exceeds 5,000 titles. Someone should acknowledge Dr. Glaser's onerous but highly useful labor.

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THE "STORY" OF NONIONIZING RADIATION RESEARCH*

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IN the past 18 months a good deal has happened to put this subject in the public eye. Right after the 1977 meeting of the International Scientific Radio Union (URSI) in Virginia on this subject, *The New Yorker* published a two-part article by Paul Brodeur on the dangers of microwaves. He took the view that our military-industrial establishment was keeping the truth from the American public. He went on to enlarge on this theme in a book with a title that reflected his sober and evenhanded approach to the problem: *The Zapping of America: Microwaves, Their Deadly Risk, and the Cover-up*.

Let me note that one ought not charge authors with inventing their own book titles—that might well be the work of their publisher's promotion department. The author may be the most reticent person in the world, but reticence does not sell books, and publishers are not in the book business for their health. Nor are authors always good judges of what is a catchy title, as I once found out to my own sorrow. In 1964 I persuaded McGraw-Hill to call a graduate text I had written with Marvin Chodorow *The Fundamentals of Microwave Electronics*. Ten years later it went out of print after selling a good 2,500 copies and my co-author's daughter, the sociologist Nancy Chodorow, said to us: "You really ought to write a sequel, with a catchier title; how about *The Son of Microwave Electronics?*"

At any rate, it fell to Don Justesen and me to review Mr. Brodeur's book in the May 1978 *IEEE Spectrum*, which is to electrical engineers what the *Journal of the American Medical Association* is to physicians—much like *The New Yorker*, but without the serious parts.

It was not a rave review. We took issue with the author on several

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points, mainly because he tended to highlight certain findings at the expense of some others. That is surely legitimate if one means to persuade, although it might not be the way to add to one's reputation for objectivity. But then, if *we* are to be objective, we must allow that such writings have their uses. Who knows whether the New York Academy of Medicine would have selected nonionizing radiation for its symposium topic this spring if it had not been for the publicity given to Mr. Brodeur's book—to which I have just added, you might have been at home, chuckling over your copy of the *J.A.M.A.*, instead of sitting here listening to some professor with a funny accent.

Now as to the history of our subject—where did it begin? For most professionals of my generation, it began in World War II, when the mass use of radio and radar first led to the realization that we had a new type of potential hazard on our hands that could affect large numbers of young men. I stress young men because such equipment was used and maintained mostly by young men. I was a radar technician myself in my early 20s, in the Eighth Air Force, and I recall the stories that circulated: a radar beam would keep you warm on a cold day, which actually worked; and a short ventral exposure just before a furlough would keep you from inadvertently increasing the local population, which didn't work nearly so well.

Radar might even be dangerous. Disconnect the antenna from an operating radar and hold a piece of steel wool in front of the waveguide connector, and it would start to glow and then to burn in a most spectacular fashion. It was common knowledge that one should not go looking up the waveguide to see whether the transmitter is on; at least use a mirror.

Since young men would continue to service and to operate such equipment after the war, a problem arose for the military services, and later for civilian communications agencies as well, a personnel problem, a morale problem: the young men *would* worry about producing offspring, this time deliberately. I am convinced that it was in part this worry that led our Department of Defense to mount the Tri-Service program in the mid-1950s.[1] No one had seen any steel wool burn or felt more than a minimal heating at microwave power densities below 100 mW/cm.^{2} The maximum permissible power density was put at one-tenth of that value, and a program was launched at a number of universities to validate that 10 mW/cm.^{2} limit and to find out—what? I am not for directed research, but that program was not even coordinated; it was everyone for himself. In one of my own experiments I went back to that ventral exposure of young males, only I used mice. I did not think I would find human volunteers, especially in Berkeley.

We irradiated hundreds of mice with 3 cm. microwaves, right up to the LD_{50}, or lethal dose 50—that is, the power density at which half the mice would die of heat stress—and then we bred the other half, the survivors.[2] Every one of them sired a litter, which led me to formulate the principle that so many G.I.s in all innocence had attempted to demonstrate empirically: that whole-body irradiation by microwaves will kill you before it makes you sterile.

Don Justesen here has recently looked at another result from that series of experiments: that for chronic irradiation below the LD_{50} (but above the maximum permissible standard of 10 $mW/cm.^2$), irradiated mice had slightly *greater* longevity than the controls.[3] Stated most simply, Justesen has confirmed my startling finding of 15 years ago that actually, below a certain level, microwaves are good for you. For one thing, a slight artificially induced fever might help the organism to withstand certain infections.

The Tri-Service program petered out in the mid-1960s, and there was a hiatus in sponsored research in this field that did not end until the early 1970s, after several new developments. Litton Industries and Raytheon learned how to make cheap magnetrons and magnetron power supplies, which are the hearts of microwave ovens. That pushed the price of such ovens below \$395. In those days no household appliance, from freezer to color TV, could find a mass market if its price was \$400 or more. (Today, that is the price of a pair of fairly good hi-fi speakers.) That brought the HEW's Bureau of Radiological Health into the act. Presently there was a whole new act: the Radiation Control for Health and Safety Act of 1968.[4]

Moreover, government and university scientists gradually became aware that a rather formidable body of literature had been accumulating in the Soviet Union and the countries allied with it. The Bureau of Radiological Health sponsored a meeting at Richmond, Va., in 1969,[5] at which Karel Marha from Czechoslovakia spoke of this work. I helped translate the book he had just written with Jan Musil and Hana Tuhá, and saw it through its American publication.[6] And then another part of our defense establishment started to take an interest in microwave bioeffects. The Tri-Service program had been concerned mainly with health hazards. Its ultimate aim was to find out how big a fence one had to put around a radar transmitter, that sort of thing—but now the military intelligence people also got busy. They had noticed article after article in the Soviet literature about the effects of exposures much lower than 10 mW/cm.^{2}—not heating now but mostly behavioral observations—and at about the same time they found out that microwaves, at these low levels, were being beamed at the American embassy in Moscow. And not a steady signal, either, but modulated in strange and mysterious ways. What did it all mean? A secret project was created to investigate the Temporarily Unidentified Moscow Signal, which our intelligence community found so hard to digest; that is doubtless why they called it by a name whose acronym is TUMS.

One reason this project was secret had to do with the diplomatic perceptions of the day. Our diplomats were dealing with their Soviet counterparts on a broad front, seeking détente. To introduce a highly controversial issue of relatively minor importance might open a whole Pandora's box of new problems and complications. These perceptions had the inevitable consequence that the entire investigation was dubbed Project Pandora.[7] The makers of our national policy may not have always succeeded in winning the world's hearts and minds, but at least we could rest secure in the knowledge that they had had a classical education.

Nothing much ever came of this project. To this day, who knows what evil lurked in the Russian mind when the Kremlin decided to irradiate our embassy? Perhaps they just wanted to make us nervous; if so, they certainly succeeded. But this episode—that, and possible leaks from the new microwave ovens—had the salutary effect of rekindling government interest in sponsoring more research, and who am I to argue with that? To be sure, much of the research sponsorship was at first aimed at very specific problems. It is only quite recently that some of this new largesse has trickled down to basic research, and you will hear about some of the directions these new fundamental investigations are taking at this symposium. We have even started some collaborative projects with our Soviet colleagues, after meeting with them at a Bureau of Radiological Health-sponsored conference in Warsaw[8] in 1973 and at URSI meetings since then.

Much credit for diverting this renewed government interest from the esoteric and absurd into useful and significant channels belongs to the selfless and persistent efforts of a relatively small number of people who serve, entirely without compensation, on a few influential committees. They are the organizers of professional meetings such as this one. They are the unsung heroes who sit through endless sessions of standards groups such as those of the American National Standards Institute and the National Council on Radiation Protection and Measurements. Above all, in this field there is the Electromagnetic Radiation Management Advisory Council (ERMAC), which is attached to the National Telecommunications and Information Administration (NTIA). ERMAC's influence actually extends well beyond the government unit to which NTIA belongs, which is the Department of Commerce. Over the years ERMAC has shown that it has no ax of its own to grind. The reviews of current research that are a part of ERMAC's public hearings are well attended and generally respected. As a result, the committee has been able to influence decisions about research funding in departments whose budgets are many times that of the Department of Commerce, such as Defense and Health, Education, and Welfare. If present-day research funding in this field amounts to several million dollars a year, and if a good portion of it is earmarked for fundamental studies, the credit must go in large degree to ERMAC. Working quietly behind the scenes, buttonholing agency heads, cajoling program directors, ERMAC has seen to it that good work goes on and receives at least *some* government support—and I don't say so merely because I sit on the Council myself.

That brings us from World War II to the present. But is that as far back as it goes? Actually, the effects of radiofrequency heating were known before the turn of the century. The big name was Jacques Arsène d'Arsonval (1851-1940), who was a pupil of the great physiologist Claude Bernard (1813-1878), and ultimately succeeded him as professor of medicine at the Collège de France.

But D'Arsonval was not only a physiologist. He had a professional interest in electrical engineering. For many years he served as the editor of a trade journal, *La Lumière électrique*. Today we would call him a bioengineer. He invented the D'Arsonval galvanometer, which remains one of the most sensitive electromechanical current meters to this day. He was one of the first to use a telephone receiver to measure electrophysiological activity in muscles and nerves. And he measured the effects of low-frequency sinusoidal currents on muscles, after first devising a method of checking just how sinusoidal the currents were. He found that at the lowest frequencies there were no contractions or pain, but oxygen absorption and production of carbon dioxide increased in the tissues. At about 10 cycles there were individual muscular contractions, two for every cycle, and then around 25 cycles the contractions fused and the muscle was contracted all the time, or, as it was then called, tetanized. The intensity of this excitation increased with the frequency, peaked at about 2,500 cycles per second, and then decreased until it was hardly noticeable at the highest frequency his machine could achieve, about 10 kilocycles.[9]

I say kilocycles rather then kilohertz because the name of Hertz was by no means well established then. In fact, these experiments were done at about the same time that Heinrich Hertz (1857-1894) did his famous experiments demonstrating the existence of electromagnetic waves, in 1887 and 1888, just over 90 years ago. Now few people realize that Hertz's experiments were done at microwave frequencies, and all sorts of experiments in what we would call microwave optics were performed with them. Not until radiotelegraphy started a few years later did it become necessary to go to longer wavelengths for communications purposes. But there was no reason to do so in laboratory experiments.

D'Arsonval realized that he had a marvelous new tool in the Hertzian waves right away, from 10,000 cycles to 1 billion—five orders of magnitude in one jump! Within three years, in 1891, he was able to report that he could get *no* physiological effect at all at these frequencies. And in 1892 he sent a paper about it to your sister institution, the French Académie de Médécine,[10] which the Academy regarded so skeptically that they nearly did not publish it. At any rate, he never sent them another paper as long as he lived, and he lived for another half century.

At about the same time, the Serbian-born inventor Nikola Tesla (1856-1943) was making similar experiments in America. He showed that oscillations around 20 kHz. could not be perceived by the human body even at power levels that would make a nearby 4-foot glow tube light up; but a metal object became heated under the influence of a high-frequency field. Incidentally, it is well known that the health of many of the pioneers of radioactivity and other ionizing sources was affected by their experiments and some of their lives were shortened, so it is worth noting that D'Arsonval, Tesla, and another radiofrequency pioneer whom I shall mention presently, Eli Thomson (1853-1937), all lived well into their 80s.

In December 1891 Tesla published an article in *The Electrical Engineer* entitled "Massage with Currents of High Frequency," in which he noted that a person connected to a source of high-frequency currents did experience heating, although he could not say whether it would be beneficial. He referred to the subject again three months later in lectures in London and Paris but on none of these occasions did he describe any actual experiments in that direction. In the 19th century electrotherapy was very popular with physicians, and Tesla's lectures excited lots of interest on both sides of the Atlantic. Dawson Turner in Britain published a simple circuit by which high-frequency fields for therapy could be produced. This circuit was probably due to Eli Thomson, who had gone with Tesla on his tour of Britain; at any rate, the circuit that appears in the next edition of Turner's *Manual of Practical Medical Electricity* of 1897 is ascribed to Thomson.[11] But after this early effort of 1891 and 1892 Tesla dropped the subject, except for a paper he gave before a meeting of the American Electrotherapeutic Association in 1898—there was an entire professional society devoted to electrotherapeutics—and there he did describe some experiments, performed on himself; but, as I say, he lived to be 87. He said the physiological effect depended on voltage, current, and wave shape, and that he had experienced not only heat but also changes in perspiration and blood circulation, and fatigue bordering on somnolescence.

Now D'Arsonval had doubtless heard Tesla's lecture in Paris. He devised a better oscillator, which came to be widely used for medical purposes. In a paper in 1893 D'Arsonval summarized his results: no action on sensibility or contractility; analgesia at the point of application of the electrodes; vascular dilatation and a drop in blood pressure; and increased metabolic rate without a rise of the central temperature but with a greater dispersal of heat at the periphery.[12]

So far, everything had been done by conduction, with the subject connected to the equipment directly. Now—still in 1893—D'Arsonval moved to induction, or what he called autoconduction. He placed an experimental animal inside the coil, and later on a human subject. The person was completely enclosed in a large, man-sized solenoid coil, with big gaps between the turns, like a cage. High-frequency current was passed through it. The person felt neither pain nor any other sensation, but if he held a lamp in his hands it became incandescent. You can see one of these cages at the Wellcome Museum in London and another at the remarkable Bakken Museum of Electricity in Life in Minneapolis. There they have a version that lifts up over one's head and down again like a bell jar. I have stood inside it, and found it to be scary.

D'Arsonval received a lot of help from Paul Oudin (1851-1923), who collaborated with him on the clinical applications of high-frequency currents. In 1892 Oudin found that a resonant coupled circuit worked especially well. That circuit, the Oudin resonator, was to play an important part in the development of radiotelegraphy in France. Oudin concentrated on the clinical application of a sort of high-voltage brush discharge, which he called the "shower of sparks," to certain dermatological conditions: eczema, acne, lupus, and various gynecological conditions. He also studied the anesthetic effect of small sparks falling on a painful part for some minutes. He found that it gave relief in neuralgia, sciatica, lumbago, and several muscular conditions. He even demonstrated, with the help of a dentist, that teeth could be extracted without pain; and he introduced the use of high-voltage, high-frequency currents in surgery, initially for the destruction of small superficial tumors.[13]

During 1894 and 1895 D'Arsonval conducted a clinical assessment. Seventy-five patients suffering from various ailments were treated. Each was placed in the solenoid for 15-20 minutes daily; in all, nearly 2,500 treatments were given. Most types of hysteria and certain forms of local neuralgia received absolutely no benefit, but for arthritic, rheumatic, and gouty conditions there was a very marked amelioration. An improvement in general health—better sleep, appetite, and energy, and an allayment of nervous symptoms—was followed by an improvement in local conditions, such as movement of a joint without pain. Examination of the urine showed improved metabolism. In three diabetics, sugar in the urine was greatly reduced.

The next step was a series of hospital trials. D'Arsonval had to transport batteries to the hospital as a prime source; these trials were made so early in the development of electrical engineering that his hospital was not yet connected to an electric power supply. He used three methods: electrodes across the thick copper coil, autoconduction by means of the large cage, and something called the condenser couch. That was a large, shaped metal plate on which the patient reclined. The patient formed one of the plates of a condenser, the metal couch itself was the other plate, and the insulating cushions were the dielectric. Other patients were treated by having conduction currents passed through them from the feet to the hands; one end of the thick copper solenoid was connected to a footbath, the other to a bifurcated terminal held in the hands. A current of 350-450 mA was used and treatment was carried out daily for six minutes. How they managed not to kill anyone we shall never know. We do know that of the first three patients, two were treated for diabetes and one for obesity.

After that we have a continuous trickle of journal articles in several countries that describe the efficacy of high-frequency currents in certain conditions and not in others. D'Arsonval's work was generally acknowledged and his apparatus was used, but from time to time it was suggested that Tesla had a prior claim as the inspirer of medical applications of high-frequency currents. In 1899 the Austrian Moritz Benedikt (1835-1920) considered Tesla's claim to priority, came down strongly in D'Arsonval's favor, and suggested the term D'Arsonvalization in his honor, to denote application of high-frequency currents, in the same way that the terms of galvanization and faradization had been used before.

Meanwhile, D'Arsonval and his assistant Albert Charrin (1857-1907) carried out a series of experiments to determine whether there was any effect on bacteria and various toxins. Cultures were placed in glass tubes within the solenoid. To eliminate thermal effects, the tube containing the culture was surrounded by ice. The results were inconclusive. Tesla continued to claim spectacular results; there was a report that he had found a cure for tuberculosis after he announced that he had killed the bacillus by high-frequency currents.

We can thus see that our subject has a long history. All this work I have been describing started in 1891, and we have not even reached the turn of the century yet. Before there were radar and microwave communications, there was high-frequency diathermy, going back to the 19th century. Good results were obtained in the amelioration of pain from sciatica and other neuralgic conditions. It was noted that there was a general sense of stimulation and increased vigor, probably because of increased circulation. There was some improvement in certain skin conditions, possibly for the same reason. But the basic mechanism was not elucidated, not even the heating.[14] D'Arsonval thought it came about as a result of chemical activity. The idea that high-frequency currents heated by molecular agitation and oscillation was not advanced for a score of years, until Karl Franz Nagelschmidt (1875-1952) published the first textbook on diathermy in 1913.[15]

Meanwhile, diathermy machines also came to be recognized as convenient instruments for electrosurgery. The blade remained cold, and the incision was automatically cauterized and dessicated; that is, the tissue was not burned but dried out—what is called fulguration. The pioneering work was done by one of your colleagues, the New York surgeon George Austin Wyeth (1877-1964), in the 1920s.[16] Another great American surgeon, Harvey Williams Cushing (1869-1939), extended the use of high-frequency currents to brain operations; and two British surgeons, Dan Mackenzie (1870-1935) and John Andersen (1886-1935), first used the method respectively to extirpate diseased tonsils and for biopsies of suspected malignancies because it killed bacteria and lessened the danger of the spread of cancer cells.

Then, in the 1930s, we had the first attempts to study the effects of short-wave radiation on animals by Joseph William Schereschewsky (1873-1940) in America; and by Erwin Schliephake (1894-19?) in Germany, who wrote a textbook on the medical applications of short waves.[17] It was a big subject in the 1930s. If you look over the program of the Sixth International Conference of Physical Medicine in 1936, you will be astonished to see how much of it was devoted to short-wave therapy. And if you look at a textbook of physical medicine of the day, you will find it raising questions about the selective action of the waves according to frequency, and whether the different dielectric constant of various tissues and organs might make for selective heating.[18] Some of those problems are with us yet. And then there was electropyrexia, or hyperthermia—in short, the induction of artificial fever to fight infection.[19] That was very big in the 1930s, and with it came a return to the methods of D'Arsonval, that is, induction by surrounding coils or condensers rather than conduction via electrodes. That is very big today, too. The effect of ionizing radiation in cancer therapy is known to be enhanced if the body temperature is raised, and that can be conveniently done by simultaneous irradiation with microwaves. One wonders how many of the researchers working on this approach know that heating the whole body in this way is illustrated in the *Archives of Physical Medicine, X-Ray, Radium* for 1932. There is a picture of the patient enclosed in a kind of zipper sleeping bag and placed between two large metal plates. One cannot be sure how much of the heat came from the waves and how much from the zipper bag.

I am told that the National Cancer Institute (NCI) became very enthusiastic about this combined ionizing and nonionizing radiation. In principle, one can direct the microwaves at a specific organ and elevate the temperature locally. The trouble is that if the cancer is localized, there are often other ways of attacking it, notably surgery; so what many of the researchers are actually seeing are metastized cases in which whole-body treatment is indicated. And for elevating the temperature of the whole body, the old zipper bag—or just a plastic garment—works quite well by itself, as NCI now recognizes.

We are now safely arrived at the present. I need not regale you with the current state of the art. It is a function of this symposium to acquaint you with that. I think the points I wanted to make are fairly obvious. First, the history of science and technology is a fascinating subject and of cultural interest in its own right. Certain patterns emerge, for instance, the interplay between technical developments and their applications in medicine or science, and it is by no means a one-way road. D'Arsonval was so far ahead of the technology of his day that he went directly to Hertz's experiments and improved on them, although he was by training a physician and a physiologist; and when the first really powerful French radio transmitter was installed on the Eiffel Tower, it turned out that the radio engineers had to come to D'Arsonval for the most advanced design to be found. And second, it pays to look at what went before. People have been looking for cellular and molecular effects of radiofrequency radiation for decades; there is a long history of side effects to look for, for example, the effects of the production of ozone from electrical discharges in the same room as the patient. Finally, it is a humbling thought that a multimillion-dollar national investment in electronic gear might have been substantially reduced by a timely purchase of a gross of plastic raincoats.

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CHAIRMAN'S INTRODUCTION: SESSION III*

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I am delighted to attend a microwave conference that includes a session on epidemiology. Those present who have not been previously exposed to the difficulties involved in laboratory research in this field have no doubt been very impressed with the problems of dosimetry and equipment design. The problems in the epidemiological studies are even more difficult than those in the laboratory, although not unique to microwave investigations. The kinds of problems faced are especially troublesome to laboratory investigators who worry about the fact that one cannot really reconstruct the dose history of an exposed population. One can do much better with mice or rats. Members of cohorts are difficult to locate. One really does not know about confounding factors. The problems faced by the epidemiologist seem formidable to laboratory scientists.

It is an interesting bit of history that the Atom Bomb Casualty Commission, from which we have derived most of the information we now have on the effects of ionizing radiation on humans, was almost put out of existence in 1950. It was the opinion of the scientific advisors to the Atomic Energy Commission at that time that the potential yield of that study, which was going to cost a few million dollars a year, was so inadequate that there really would not be any point in pursuing it. That recommendation was made in 1950 but, fortunately, was overruled. We are in a much better position today because of the information that has come out of that very difficult study.

In the case of the internal emitters, many hundreds of millions of dollars have been spent on laboratory investigations, but the best information we have about the effects of the bone-seeking radionucleides comes from studies of the radium dial painters who ingested radium during World War I.

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Other examples of the value of epidemiology can be found in the area of chemical toxicology. Only through recent epidemiological work have we begun to realize that low levels of exposure to lead retards the learning ability of children. This is a very important finding in view of the many children who absorb lead through the habit of pica. The angiosarcomas discovered among vinyl chloride workers were also found by epidemiological studies.

I started out in this field in the days when there were many mysteries about silicosis. It was very difficult to produce pulmonary silicosis in experimental animals. The most useful information about that disease was obtained as a result of epidemiological studies. The same is true of the mesotheliomas seen among persons exposed to asbestos.

Over the years much of the information needed at the practical level of public health control, both in the field of chemical toxicology and ionizing radiation exposure, has come from epidemiological studies. This is not to say that the laboratory work is not enormously important. It must be supported and, in this field particularly, we must expand the work. In the laboratories we can learn about the underlying basic mechanisms. We can study the shapes of dose-response curves. Such work gives the epidemiologist the necessary clues as to what to look for. Above all, this kind of research adds to our understanding of basic life processes.

We must bear in mind that we are entering a decade in which many public policy decisions will be made. These will involve such questions as what to do about saccharin and what regulations to establish concerning permissable levels of exposure to microwaves and ionizing radiation. I see little prospect that the excellent laboratory work that is being done will provide the kind of information that will be needed to answer such questions. The information must come from epidemiological research. I emphasize again that both have to go on, but the epidemiological research will provide most of the information needed to put public policy decisions on a rational basis.

EPIDEMIOLOGIC APPROACH TO THE STUDY OF MICROWAVE EFFECTS*

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I was asked to include in this presentation a report of a recently concluded epidemiologic study of occupational exposure to radar during the Korean War.[1] Before getting to the study, I shall give a brief account of the objectives and methods of epidemiology and their application to the investigation of microwave radiation effects.

GENERAL EPIDEMIOLOGY

Ever since epidemiology became broader than the study of epidemics, a simple definition has failed to convey the nature and scope of the field. It is the study of both the distribution and the determinants of disease (or any health-related condition) in defined groups of individuals or the population.[2] The study of the distribution of disease in terms of age, sex, race, geography, environment, occupation, socioeconomic status, and other characteristics is essentially descriptive; investigation of the influence of these and other factors on disease patterns is analytic, a search for causes.

Epidemiology is one of many disciplines that search, each in its own fashion, for causal factors in health and disease. Because many levels of influence lead to disease, and disorders rarely are due to one cause alone, many types of knowledge are needed. In epidemiology, a science basic to public health and important to medicine, the search is for determinants that can be modified to prevent disease or ill health. Interest covers the whole spectrum of disease from an inapparent or subclinical state through frank illness to death. Epidemiologic evidence about etiology may be incomplete

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TABLE I. EPIDEMIOLOGIC STUDIES

Characteristics of data	
	Defined groups of individuals or the population
	All cases in a defined population
	Rates of observations
	Same information for cases and controls
Types of studies (observational)	
	Demographic
	Cross-sectional (prevalence)
	Cohort (prospective, longitudinal)
	start with population and seek cases over time
	Case-control (retrospective)
	start with cases and refer back to populations

or inconclusive but may still provide a reasonable basis for preventive action as well as for further study aimed at improvement of our understanding of causation.

Some features of epidemiologic studies are shown in Table I. In contrast to clinical medicine, which deals with individual cases or a series of cases, epidemiology is concerned with all cases, or a representative sample of them, in defined groups of individuals. Cases are related to the population group and the time period in which they occur; the reference population is as necessary as the cases of interest. Several basic rates measure the frequency of disease and deaths. For example, morbidity rates, in terms of occurrence (incidence) or prevailing frequency at a particular time (prevalence), and mortality rates make it possible to compare the health experience of different groups of individuals. And, of great importance in epidemiologic studies, the same quality of information is needed for cases and controls.

In the main, methods used in search of etiologic factors are those of observational rather than experimental studies. A study may be suggested by the findings of descriptive epidemiology, clinical investigation, experimental work, or other sources. A tentative hypothesis is followed by demonstrating a statistical relation between the condition under study and certain individual or group characteristics. Then, the meaning of the relation must be established. If causal inferences are derived, they are tested in studies of individuals with the condition or characteristic compared to those without it. Two principal approaches are used: studies can start either with a given population in which cases are sought over time (cohort, prospective) or with cases which are referred back to their population groups (case-control, retrospective). There are advantages and disadvantages to both types of studies, as well as different indications for their use and differences in the type and quality of information produced.

The strength of epidemiology is its ability to provide a direct measure of risk in humans. Risk estimates from nonhuman experimental studies may require epidemiologic confirmation and for some diseases experimental studies cannot be done at all because there are no suitable animal models. Adequate risk information cannot be furnished by clinical medicine alone.

The limitations of epidemiology are those of a population-based life science. Information must come from many other disciplines such as clinical medicine, pathology, environmental sciences, and statistical and social sciences. More often than not, data sources have been developed for other purposes. There can be considerable variation not only in the quality and quantity of data but also in the availability and completeness of records. And the epidemiologic method may be impractical to detect some low-level risks because of large sample-size requirements and problems of identifying and controlling confounding variables.

Epidemiologic Studies of Microwave Effects

Epidemiologic studies of microwave effects have been few in number and limited in scope; two recently completed cohort studies will be reported at this session of the symposium.[1,3] People occupationally exposed in the military services or in industrial settings have been the principal groups studied. A few other populations living or working near generating sources or exposed to medical diathermy have been or are being investigated.

Information about health status has come from medical records, questionnaires, physical and laboratory examinations, and vital statistics. Sources of exposure data include personnel records, questionnaires, environmental measurements, equipment emission measurements, and (assumed adherence to) established exposure limits. Microwave dosimetry presents formidable problems in assessment. There is at present no practical way to determine exposure to large numbers of individuals or to determine absorption or distribution of absorbed energy in humans. Epidemiologic approaches to some reported or suspected adverse effects, none of which appears pathognomonic for microwave radiation, will be presented.

Ocular Effects

Many surveys of ocular effects in man have been made, especially in the United States. Most investigations have involved service personnel and civilian workers at military bases and in industrial settings. The principal subject of interest has been the significance of minor lens changes in the cataractogenic process; cataracts (opacities impairing vision) have been infrequently investigated, and only recently have retinal changes been looked for.

Minor lens changes. Lenticular defects too minor to affect visual acuity have been studied as possible early markers of microwave exposure or precursors of cataracts. Studies have been mainly prevalence surveys, although the time periods are often variable or not specified; re-examination data rarely permit estimates of incidence. These occupational studies have generally emphasized careful clinical eye examinations, including the use of slitlamp biomicroscopy and photographs, without comparable attention to study design and follow-up plans for exposed and comparison groups.

The following generalizations can be made about observations of lens changes in microwave workers and comparison groups:

1) Lens imperfections occur normally and increase markedly with age among all employed men studied. There is evidence that lens changes increase with age even during the childhood years.[4] By about age 50, lens defects have been reported in most comparison subjects. This is illustrated in the scatter diagrams (Figure 1) based on data from various studies.

2) Although a few suggestive differences have been reported,[4-6] there is no clear indication that minor lens defects are a marker for microwave exposure in terms of type or frequency of changes, exposure factors, or occupation. Inspection of Figure 1 suggests possible earlier appearance of lens defects among microwave workers than among comparison groups, but there is considerable variation in the type, number, and size of defects recorded, in the scoring methods used by different observers, and in the numbers examined.

3) Clinically significant lens changes, which would permit selection of individuals to be followed, have not been identified.[7]

4) There is to date no evidence from ophthalmic surveys that minor lens opacities are precursors of clinical cataracts.

Cataracts. Although there has been much interest in the cataractogenic

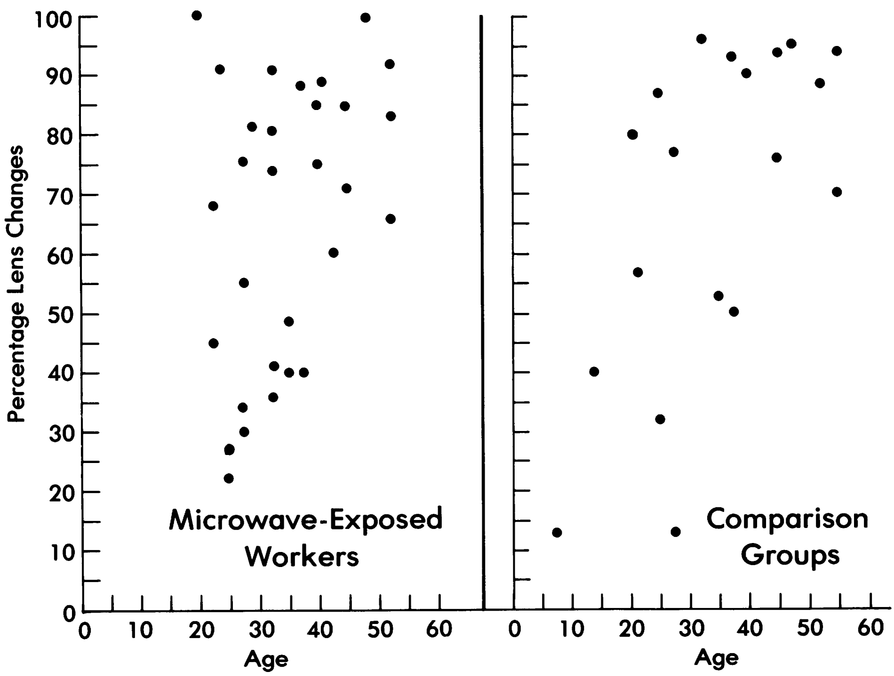

Fig. 1. Percentage lens changes (all types) by age: various studies

effect of microwave radiation, only minimal effort has been made to investigate cataracts as such, as distinct from their precursors. The only epidemiologic study of cataracts in microwave workers, a case-control study of World War II and Korean War veterans with negative findings, was reported in 1965.[8] A recent statement that "not one epidemiologic study...suggests even a slight excess of cataracts in microwave workers"[9] is certainly true because there has been only one study.

Neither definitions nor methods of detection of cataract are standardized. The common meaning of cataract, a lens opacity that interferes with visual acuity, is open to many interpretations as to degree and nature of the opacity and loss of visual acuity. Specific disorders, physical agents, and injuries are known to cause cataracts, but many cataracts are loosely called senile when they occur after middle age, implying they result solely from aging of the lens. Microwave cataracts are, in the opinion of most observers, not distinguishable from other cataracts.

The most prominent characteristic of cataracts is their age distribution.

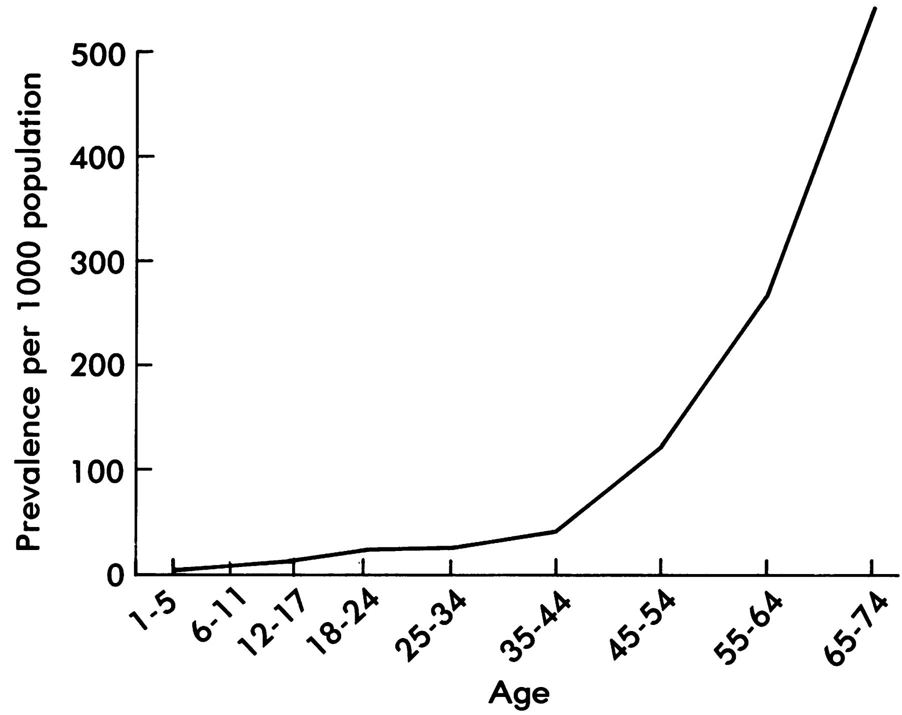

Fig. 2. Prevalence by age of one or more types of cataracts among persons 1 to 74 years of age, United States, 1971-1972. Preliminary national estimates. Source: National Center for Health Statistics, Division of Health Examination Statistics, Medical Statistics Branch, March 2, 1979.

Although estimates of frequency are not comparable because of differences in population groups surveyed, as well as nonuniform methods of detection and definition, all point to low frequencies until about the fifth decade of life when sharp increases occur.

Preliminary national estimates by age of the total prevalence of cataracts in the civilian noninstitutionalized population 1 to 74 years of age in the United States have recently been made available by the National Center for Health Statistics.[10] They are based on diagnoses by ophthalmologist examiners in the Health and Nutrition Examination Survey of 1971-1972 and are shown in Figure 2.

One or more cataract conditions were found in 9% of the population. For the various age groups under 45, frequency increases gradually from 0.4% in those 1 to 5 years of age to 4% in the 35-to-44-year age group. The marked increase that occurs after age 45 reaches a maximum in the oldest group examined: of those 65 to 74 years of age, more than half had cataracts.

Cataract data for personnel on active duty in the armed services (who are mainly healthy, relatively young men) are available as incidence rates which show similar age dependence up to about age 55. Although not comparable with general population figures, recorded mean annual incidence rates are extremely low, of the order of two per 100,000.[11]

In the one case-control study of cataracts mentioned earlier,[8] armed services personnel with cataracts ascribable to a nonmicrowave factor were eliminated from the sampling plan, that is, all congenital, traumatic, diabetic, and other specified types. The sampling plan also eliminated veterans 55 years of age and over to minimize dilution of the study group by senile cataracts.

Studies of microwave workers have been designed to find out whether cataract formation is accelerated in younger people. It may be necessary to look at possible increases in all cataracts by age to detect possible heightened microwave-induced susceptibility. The determinants of the microwave cataractogenic effect are not fully understood[12] and the epidemiology of cataracts has been inadequately studied.[13]

Retinal lesions. Until recently, retinal lesions have not been considered a possible microwave effect. There is some reason to think that oculists examining microwave workers have observed but not reported retinal changes, because no relation to microwave exposure was known.[14] A small Swedish study reported in 1975,[15] which included examinations for retinal as well as lens changes, was prompted by preliminary findings of paramacular and macular disease among industrial radar workers. A significantly higher proportion of retinal lesions was found among microwave workers aged 26 to 40 years than in controls. The retinal lesions had resulted in decreased vision in two cases. No further reports are available.

Nervous and Behavioral Effects

The many clinical and laboratory studies from the USSR and other Eastern European countries provide important information but no firm evidence of specific microwave effects on neurologic, mental, or behavioral performance.[14,16,17] Clinical studies of groups employed in the operation, testing, maintenance, and manufacture of microwave-generating equipment have involved mainly low-level (microwatts or a few milliwatts) and long-term exposures. With few exceptions, functional disturbances of the central nervous system have been described as a typical kind of radiowave sickness, the neurasthenic or asthenic syndrome. The symptoms and signs include headache, fatigability, irritability, loss of appetite, sleepiness, sweating, thyroid gland enlargement, difficulties in concentration or memory, depression, and emotional instability. This clinical syndrome is generally reversible if exposure is discontinued. Another frequently described manifestation is a set of labile functional cardiovascular changes including bradycardia (or occasional tachycardia), arterial hypertension (or hypotension), and changes in cardiac conduction. This form of neurocirculatory asthenia is also attributed to nervous system influence. More serious but less frequent neurologic or neuropsychiatric disturbances have occasionally been described as a diencephalic syndrome.

The only American epidemiologic study thus far of some of these effects is the cohort study of American embassy employees in Moscow and comparable groups in embassies of other Eastern European capitals[3] which will be reported by Dr. Herbert Pollack. No differences were attributable to microwave exposure at the intensities measured outside the Moscow embassy (1-18 $\mu W/cm.^2$). These levels, however, were even lower than exposures reported in the Russian occupational studies (microwatts up to about 4 $mW/cm.^2$).

The identification and assessment of poorly defined, nonspecific complaints, symptom complexes, and illnesses is extremely difficult.[18,19] In addition to medical examinations, consultation with specialists in the behavioral sciences is needed. The use of health questionnaires designed to detect emotional ill health and objective psychologic tests for specific types of symptoms can provide relevant information. Useful data may also come from attendance rates at clinics or physicians' offices, absentee rates due to illness, accident liability, and job performance.

Congenital Anomalies

A case-control study of Down's syndrome in Baltimore[20] yielded an unexpected finding regarding paternal exposure to microwave radiation. Fathers of children with mongolism more frequently gave unsolicited histories of occupational exposure to radar during military service than did fathers of unaffected children, a difference that was of borderline statistical significance. Exposure during military service occurred prior to the birth of the index child. After publication of the first report in 1965, expansion of the study group, follow-up of all fathers to obtain more detailed information about radar exposure, and search of available armed forces records were undertaken. The suggestive excess of radar exposure of fathers of Down's syndrome cases was not confirmed on further study but occupational exposures were difficult to document.[21] A chromosome study of peripheral blood of exposed and unexposed fathers showed some suggestive but inconclusive changes; the findings are to be reported.

A study of congenital anomalies in Alabama[22] showed that during the three-year period 1968-1971 the adjoining counties of Dale and Coffee, in which Fort Rucker was located, had a reported number of clubfoot cases among white babies that greatly exceeded the expected number (based on birth certificate notifications for the state). More detailed investigation revealed that in the six-county area surrounding Fort Rucker there was, during the same time period, a considerably higher rate of anomalies (diagnosed within 24 hours after birth) among births to military personnel than in the state as a whole. Fort Rucker was a training base for fixed wing and helicopter aircraft, situated within 35 miles of dozens of radar stations. Errors in malformation data on birth certificates and probable over-reporting from Fort Rucker led to the conclusion that convincing evidence was lacking that radar exposure was related to congenital malformations.[23] The high malformation rate across a group of counties of the state was presumably environmentally induced but no specific agent was suggested. It was not possible to do a more detailed study at this or at another military base.

The use of microwave heating as diathermy to relieve the pain of uterine contractions during labor was reported from Belgium in 1973.[24] The analgesic effect was helpful in 1,000 selected patients without obstetric disease, and the babies were born healthy with good circulation. By 1976[25] 2,000 microwave-exposed patients and 2,000 controls had been observed. No untoward immediate or long-term effects on the fetus are known from such exposure shortly before delivery. The only possible congenital defect so late in gestation would involve the central nervous system. Systematic follow-up examinations have not yet been made.

CANCER

Microwave-induced cancer has not been reported experimentally or suspected in medical surveillance examinations of microwave workers or military service personnel. Only the two recently completed prospective epidemiologic studies[1,3] to be reported at this session have looked into the question systematically. Neither has revealed an excess of any form of cancer thus far that can be interpreted as microwave-induced. A description of the occupational study of Navy servicemen follows.

Study of Occupational Exposure to Radar in the Navy[1]

In 1970-71 we did a pilot study to determine the requirements and feasibility of a cohort study of health risks from microwave radiation. The study was to make use of differences in levels of occupational exposure and of medical information recorded during military service and after discharge. We proposed to study Navy enlisted men and to investigate their total mortality and morbidity experience, reproductive performance, and the health of their children.

The pilot work was done in collaboration with the Medical Follow-up Agency of the National Academy of Sciences and with the assistance of various Navy specialists. We found the proposed investigation feasible but the cost of studying all factors of interest very high. After several modifications of the study plan to conform with available funds, a protocol was developed which involved the use of largely automated military and veterans' records to analyze a limited number of endpoints: mortality, hospitalized illness in naval and veterans' hospitals, and disability. The study, recently completed under contract with the National Academy of Sciences, is being prepared for publication.

Selection of study population. Since World War II the Navy has maintained technical schools where thousands of enlisted men have been trained in the use and maintenance of radar equipment for navigation and gunfire control. Large numbers of servicemen similarly selected for educational achievement, general intelligence, and aptitude have also graduated from other technical schools, thus offering the possibility of selecting valid comparison groups. The records of the technical schools, available at the Military Personnel Records Center in St. Louis, identify graduates of specific training programs; these graduates were used to construct rosters of study subjects. Men selected for this study graduated during the period 1950 through 1954. The Korean War period was chosen for two reasons: wartime service ensured virtually complete ascertainment of deaths, and exposure during the 1950s provided a sufficient time for long-term effects.

Measurements made by the Navy offered a guide for selecting the most

TABLE II. NUMBER OF STUDY SUBJECTS BY NAVAL ENLISTED CLASSIFICATION OF OCCUPATIONS AND EXPOSURE CLASS

Potential high exposure (equipment repair)	
Electronics technician	13,078
Fire control technician	3,298
Aircraft electronics technician	3,733
	20,109
Potential low exposure (equipment operation)	
Radioman	9,253
Radarman	10,116
Aircraft electrician's mate	1,412
	20,781

highly exposed occupations. On the basis of a consensus decision by Navy personnel involved in training and operations, occupational groups were classified as probably maximally exposed (those repairing radar equipment) and probably minimally exposed (those operating radar equipment). Technical occupational groups probably nonexposed (such as engine-room personnel) were considered unsuitable because of their exposure to heat and humidity stress. Men selected for the study were drawn from six Naval Enlisted Classifications of occupations as shown in Table II.

The high-exposure cohort is made up of electronics technicians, fire-control technicians, and aircraft electronics technicians. The low-exposure cohort, consisting of men trained in equipment operations, are classified as radioman, radarman, and aircraft electrician's mate. Of a study population of approximately 40,000, there are about 20,000 in each of the two cohorts. The groups were composed predominantly but not exclusively of young men who entered service shortly after graduating from high school. The mean age of the total low-exposure men was 20.7, whereas the average of the high-exposure group was 22.1 years.

Medical information. Follow-up medical information was derived from search and linkage of Navy and Veterans Administration records. The death of almost every war veteran is a matter of record in Veterans Administration files, because applications for burial benefits are made for about 98% of war veterans. The application usually includes a copy of the death certificate, from which the certified cause of death may be obtained. The Navy's records of hospital admissions were searched, and records of admissions to Veterans' Administration hospitals were available for computer search, as were current awards for disability compensation. The cohorts of more than 40,000 men were followed through extant records for the following endpoints and time periods of ascertainment:

Mortality	1955-1974
Morbidity (in-service hospitalization)	1950-1959 (excl. 1955)
Morbidity (VA hospitalization)	1963-1976
Disability compensation	1976

Assessment of exposure. It is unfortunate that the lack of dosimetry for occupational exposure has not permitted assignment of exposure doses to any individuals in this study. The only measurements possible are environmental, or arise out of efforts to reconstruct the circumstances of accidental overexposure. There have been enough accidental exposures at estimated levels exceeding 100 mW/cm.^{2} to indicate that there are occupations in which some men at some times on certain classes of ships have been exposed well in excess of the 10 mW/cm.^{2} limit.[26] Shipboard monitoring programs in the Navy since 1957 show that men in other occupations rarely, if ever, were exposed to doses in excess of this limit.[27] Radiomen and radar operators (our low-exposure group), whose duties keep them far from radar pulse generators and antennae, were generally exposed to levels well below 1 mW/cm.^{2}, whereas gunfire control technicians and electronics technicians (our high exposure group) were exposed to higher levels in the course of their duties.

In addition to occupation per se, other relevant elements of exposure were included in the analysis, namely, length of time in the occupation, class of ship, and power of equipment on the ship at the time of exposure. To obtain information on these items, it was necessary to review individual personnel records. Because this procedure was both costly and time consuming, it was done only for men in the high exposure occupations who died from nonaccidental deaths and for a randomly selected 5% sample of living men in the same occupations.

An index of *potential* microwave exposure to individuals, called the Hazard Number, was constructed for those men whose individual records were reviewed. This consisted of the sum of the power ratings of all gunfire-control radars aboard the ship or search radars aboard the aircraft to which the technician was assigned, multiplied by the number of months of assignment. To create the Hazard Number for an individual it was necessary to trace his service assignments from ship to ship or squadron to squadron. The Navy made available information concerning the radar

TABLE III. PERCENTAGE DISTRIBUTION OF NAVAL ENLISTED PERSONNEL IN OCCUPATIONS IN THE HIGH EXPOSURE GROUP BY EXPOSURE HAZARD NUMBER

Hazard number	*Electronics technician*	*Fire control technician*	*Aircraft electronics technician*
-0-	28.0	6.6	13.0
1-2,000	28.4	23.8	16.9
2,001-5,000	19.9	30.9	18.0
5,000+	10.8	26.6	48.3
Unknown	12.9	12.1	3.8
Total	100.0	100.0	100.0

equipment in service on each ship or patrol aircraft type at various times.

The Hazard Number, then, is a measure not of actual, but of potential exposure. A technician with a low Hazard Number had little opportunity for substantial exposure to microwaves, while men with large Hazard Numbers may have had substantial opportunity for such exposure. The distribution of Hazard Numbers by specified occupational rating in the high exposure group is shown in Table III. It is evident that within the high exposure group the fire control technicians and the aircraft electronics technicians had much larger proportions of men with large Hazard Numbers than did the electronics technician group.

Results. Differential health risks associated with potential occupational exposure to radar in the Navy more than 20 years ago are not apparent with respect to long-term mortality patterns or hospitalized illness around the period of exposure, two endpoints for which there is virtually complete information for the total study group. Later hospitalization (in Veterans Administration facilities only) and awards for service-connected disability, the two other endpoints examined, provide incomplete information. While some significant differences among the occupational groups classified by level of potential exposure have been found with respect to all the endpoints studied, the differences could not be interpreted as a direct result of microwave exposure.

Because no measures of *actual* as opposed to *potential* exposure were available, the so-called "high exposure" rosters were made up of a mixture, in unknown proportions, of men whose actual exposures varied from high to negligible. If a large proportion of the men had, in fact, very small exposures, the consequence would have been to obscure by dilution any differences which might have been found had it been possible to study a large group of men who actually received high exposures. Further, it is possible that effects involving the cardiovascular, endocrine, and central nervous systems are transient, disappearing with the termination of exposure or soon thereafter, or are not perceived to be of sufficient consequence to result in admission to hospital.

It was not possible in this study to determine hospitalization outside the Navy and Veterans Administration systems, nonhospitalized medical conditions during and after service, reproductive performance and health of offspring, or employment history after discharge from service. A subsample of living men with high and low exposure patterns during service, however, can be identified for intensive individual followup. This would make it possible to obtain additional information about occupational exposure by reviewing individual service files and by making direct inquiries of the men.

Suggestions for Further Research

In view of the exceptional difficulty in extrapolating microwave effects from experimental animals to man, epidemiologic studies, including appropriate clinical and laboratory examinations, are essential to improve our understanding of possible hazards to health.

1) Studies of identified populations should be improved, continued, or expanded wherever possible and useful. It is difficult to identify exposed populations, to select suitable controls, and to obtain exposure data. Some study groups already characterized can be improved by the acquisition of additional exposure data, some groups should be followed for longer periods of time, and some should be investigated for additional endpoints.

2) Additional study populations should be sought. Exposure to microwave radiation has been experienced increasingly for more than three decades. A careful search should be made for exposed groups not yet investigated or considered for study. In epidemiologic studies, as in experimental or clinical work, there is rarely a single study, positive or negative, that can be accepted as definitive. Replication and validation are needed at all exposure levels.

3) Some specific endpoints should be studied further:

a) Cataracts. It is reasonable to hypothesize and feasible to investigate a synergistic or additive action of microwaves in cataract formation. Comparative frequencies of cataracts from all causes in exposed and nonexposed occupational groups can be investigated by following study subjects into the older age periods, when cataracts increase in frequency.

b) Mental and behavioral changes. The numerous reports from Eastern Europe of a wide variety of functional changes and possible nervous system effects have yet to be confirmed or rejected. In appropriate epidemiologic studies, medical reports should be augmented to include assessment of emotional and psychologic status.

c) Congenital anomalies. There have been two preliminary and inconclusive epidemiologic investigations of the effect of paternal exposure to radar on the occurrence of congenital anomalies in their offspring. The subject needs more intensive investigation to assess possible genetic effects.

d) Malignancies. There is no direct evidence that microwaves are carcinogenic, but the possibility has not been excluded experimentally. More intensive and extended morbidity monitoring may provide pertinent information.

To clarify the complexities of the biologic and health effects of microwave radiation, all possible study approaches are needed. Epidemiologic research, which is in an early state of development, should be broadened. As noted[28] "...as far ahead as one can see, medicine must be building, as a central part of its scientific base, a solid underpinning of biostatistical and epidemiological knowledge. ...impressions are essential for getting the work started, but it is only through the quality of the numbers at the end that the truth can be told."

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EPIDEMIOLOGIC DATA ON AMERICAN PERSONNEL IN THE MOSCOW EMBASSY

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I had prepared a long paper to present, but after yesterday's discussions, it was evident that there is so much misunderstanding about the basic facts that I shall deviate from my prepared text and present a historical background to the so-called "Moscow" situation to put the problems in context and in perspective as to what actually occurred.

The United States started relations with the Soviets during World War II and established a Lend Lease mission in Moscow. This mission was housed in a building on the Moscow River close by the Kremlin, right next door to the British and other embassies.

When finally full diplomatic relations were established, an embassy replaced the mission. The ambassador always lived in a house many miles from the chancery buildings and most of the people who worked in the chancery lived in apartment houses from two to four miles from the chancery. There were a variety of conditions under which people lived with respect to exposure to any environmental contaminant.

In 1952 the Soviet government asked the United States to move its chancery building from the neighborhood of the Kremlin to Chekovsky Street, several miles away. An empty apartment house had been reconstructed for the use of the American chancery. The Soviets had an opportunity to rebuild this building from the inside, but that is part of another story.

Periodic electronic surveillance of all of the offices in the chancery was carried out. In the course of these routine electronic sweeps, in 1953, a very peculiar signal was picked up. At first this signal was intermittently

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present. It varied in frequency from about 2 gigahertz to 7 gigahertz, it came on in a series of modes without any definite pattern and appeared and disappeared without any apparent regularity. In the late 1950s this signal became constant. The use of the electronic surveillance, or sweeping, equipment was a function of Department of Defense personnel assigned to the embassy. (Various military attaches are present in all the embassies.) About the end of the 1950s and in early 1960, the State Department decided to take over complete surveillance of this peculiar type of microwave signal which was now present in the embassy on a very definite and routine basis. A system was set up whereby continuous tape recordings were made in all four areas—north, south, east, and west—of the chancery building on a 24-hour basis. Periodically, spectrum analyzers, bolometers and other equipment measured the actual intensity and identified the various frequencies. Anytime a deviation occurred on the strip recording, a new measurement was made to see just in what direction these changes were taking place. An essentially continuous record exists of the microwave beam which was focussed on the chancery from about 1962 to date, and it is still going on.

From 1953 until May 28, 1975 there was a single source beam illuminating the west facade of the chancery building starting at about the sixth floor, peaking at around the tenth floor and the roof. The north, south, and east had no evidence of any beaming whatsoever. By using a directional antenna, one could identify the source of the beam very quickly. There was a horn on the balcony of a Soviet apartment house. Those of you who have read the Johns Hopkins Report should note the footnotes in Appendix II, which describe the intensity of the radiation beam. The maximum intensity up to May 28, 1975 was 5 microwatts. To achieve a 5 microwatt exposure the individual had to stand in front of an open window fully undressed for a full part of the working day. The characteristics of microwaves are such that once away from the open window, inside the room, a variety of field intensities fluctuate depending upon the wall, the furniture, the presence of steel cabinets, and so forth.

A few feet from the window, the intensity was down to fractions of a microwatt most of the time with occasional points there where one could measure one or two microwatts. In reporting the story up to now, we have always used maximum intensities because of having been accused of trying to cover up facts. The values to which people were actually exposed routinely were indeed much lower than the maximum readings. And in

Moscow, where it is 45° below zero, centigrade and Fahrenheit, for weeks and weeks at a time, I question whether anybody stood in front of an open window dressed or undressed.

By the end of May of 1975 there were indications that the Russians were going to change this illumination of the chancery buildings. Soon two beams appeared hitting the embassy, one from the east on the other side of Chekovsky Street and one from the south from a high rise Soviet building. And by the use of a directional antenna, these sources were very quickly located and the intensities and frequencies were measurable and recorded. The intensity increased to a maximum at one point and in one place of $18\mu W/cm.^2$, in one part of the building on the southeast corner, where two beams converged into a room. The rest of the building did not really get a full $18\mu W$ at any time. However, we adhered to the principal of discussing maximum exposure for the benefit of avoiding the accusations of cover up and minimization.

With this background and remembering that most people did not live in the chancery, there were about 12 apartments where people had some exposure to microwaves during the daytime. But the rest of the 300 some odd people at the embassy lived away from the chancery buildings and they had no exposure whatsoever.

A number of people worked on the ground floor of the chancery and had absolutely no exposure. The estimate of the exposure indices, reported in the Johns Hopkins report, is based upon these placements. Individuals' working offices were located by assignment, their living quarters were located and based upon these measurements, the maximum possible dosage which they could have received over the period of time was calculated.

Most people served an average tour of duty of two years, and many served two tours, that is four years. Others served as long as three tours, or six years, in this Moscow environment, not continuously but intermittently over a period of time.

The object of the Johns Hopkins study was to compare morbidity and mortality exposure of Foreign Service employees who had served in the American Embassy in Moscow during the period 1953 to 1976 with employees who had served in other selected Eastern European embassies or consulates during the same period of time.

Microwave exposures at the chancery building in Moscow varied during this time. Prior to May 1975 there was a single source of radiation which illuminated the west facade, essentially from the 6th floor to the roof at a maximum of 5μW/cm.^{2} about nine hours each day. From the end of May 1975 to early February 1976 there were two sources of radiation, one illuminating from the south and one from the east. The maximum measured level at one point was 18μW/cm.^{2} for 18 hours each day. Relative power levels were recorded continuously from early 1963 on a strip chart recorder. Apartment complexes in Moscow distant from the chancery were monitored at frequent intervals. Tests for microwave radiation at all Eastern European posts included in the study were made periodically using appropriate techniques.

The study itself is a broad survey of mortality and morbidity among the employees and their dependents with special emphasis on illnesses, conditions, or symptoms allegedly associated with exposure to microwaves, i.e., asthenic syndrome and others. The information came from two main sources: The medical records in the Office of Medical Services at the State Department. These were in excellent shape because each Foreign Service officer has a complete physical examination, including blood count, about every two years. A health history questionnaire was sent from Johns Hopkins to each employee who could be located. A concerted effort was made to obtain a death certificate for every deceased study subject. The study population was 4,388 employees and 8,283 dependents. More than 1,800 of the employees had worked at the Moscow Embassy. More than 3,000 of the dependents were or had been living in Moscow. About one third of the employees in the study have been followed 15 to 20 years. An average tour of duty was two years, about 23% served more than one tour, up to 8 in a few instances; 42% served less than two years.

The mortality experience can be summarized very briefly. Obviously, the most important health effect on a population would be reduced longevity or early death. Although there were 152 deaths among male employees studied, this is estimated to be only 50% of the mortality based on United States population mortality rates for white men. No differences were observed between the Moscow and comparison groups either in total mortality or in mortality from cancer, which was proportionately more frequent than the other causes of death in both groups, but still somewhat less in the Moscow and somewhat higher in the comparison group than expected from American mortality statistics.

The mortality experiences of the female employees were not as favorable as observed for the males (better than the standard United States) and the 42 observed deaths represented 80% of the expected mortality based on the American population experience.

Alterations in the health status of a population produced by the introduction of some health hazard would, in all likelihood, be detected first by an increase in the frequency of nonfatal conditions, particularly in a group examined as frequently as this group. Hundreds of comparisons were made based on information obtained in the medical records. The risks of developing health problems were shared nearly equally by both the Moscow and comparison groups. Two differences did stand out: the Moscow male employees had a three-fold higher risk of acquiring protozoal infections (Giardia) than the comparison employees and both men and women in the Moscow group had a slightly higher frequency of most of the common kinds of health conditions reported. No consistent pattern of increased frequency in the group exposed to other than background microwave radiation could be found. An analysis of the health history questionnaire brought out some different indications. The Moscow group, especially the men, reported a variety of symptoms after their study tour more frequently than the comparison group, i.e., more depression, more irritability, more difficulty in concentrating, and more memory loss. However, no relation was found between the occurrence of these symptoms and exposure to microwaves.

Congenital anomalies in children were studied. Although some anomalies occurred, no difference could be detected between the two study groups.

The Johns Hopkins group summarized their report* as follows: "To summarize, with very few exceptions, an exhaustive comparison of the health status of the State Department employees who had served in Moscow with those who had served in other Eastern European posts during the same period of time revealed no differences in health status as indicated by their mortality experiences and a variety of morbidity measures. No convincing evidence was discovered that would directly implicate the exposure to microwave radiation experienced by the employees at the Moscow embassy in the causation of any adverse health effects as of the time of this analysis."

*Lillienfeld, A.M., Tonasha, J., Tonasha, S., et al.: *Foreign Service Health Status Study. Evaluation of Health Status of Foreign Service and Other Employees from Selected Eastern European Posts.* Springfield, Va., Nat. Tech, Inform. Service, 1978.

CLINICAL APPLICATIONS OF MICROWAVE RADIATION: HYPOTHERMY AND DIATHERMY*

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I shall discuss the clinical applications of microwave radiation as related to hyperthermy and diathermy as related to basic issues concerned with their clinical use. In terms of the concepts of this symposium, I shall consider the term hyperthermy to relate to an increase in the temperature of localized areas of the body, as opposed to increasing the temperature of large body segments or of the whole body. Similarly, we regard diathermy as a generic term which includes short and long wave diathermy, microwave, and ultrasound.

The first determination a physician who uses a drug or device to treat patients must make is one which will have considerable effect and possible fallout on the end results of his treatment. Such a determination is based on the physician's knowledge of the "safety and efficacy" of the drug or device for its intended use, an intended use clearly defined under the indications for the use of the particular drug or device. In the case of diathermy devices, the agency originally relied upon the indications and contraindications for the use of diathermy published by the American Medical Association in 1950 under the title *Handbook of Physical Medicine and Rehabilitation.*[1] By 1965 the agency had recognized that the information contained in this publication was insufficient and did not reflect the state of the art for 1965. During the next 10 years we devoted considerable time and effort to determining the current state of the art. Our efforts were materially assisted by Dr. Justin Lehmann and his people at the University of Washington in Seattle, with the concurrence of the American Academy of Physical and Rehabilitative Medicine. While Dr.

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Lehmann's report dealt only with shortwave diathermy, we believe it is also applicable to the use of microwave diathermy.[2]

As a result of its investigation, the agency has concluded that the safety and effectiveness of diathermy devices is related solely to the production of heat. The agency has been aware of various advocates who claim that a nonthermal effect exists. Reviews of research studies submitted to the Food and Drug Administration (FDA) have failed to support such a concept. All the diathermy studies we have reviewed and analyzed, including numerous studies offered in support of this nonthermal concept, fail to substantiate the therapeutic claims made for any nonthermal effects. If such effects do exist, they will remain unknown until more sophisticated scientific technology can identify and isolate them.

The indications which the agency considers acceptable for therapeutic diathermy are as follows: The use of diathermy is an adjunct procedure to produce tissue heat that may be used with conventional methods of treatment in the following conditions:

1. Secondary muscle spasms in musculoskeletal disease
2. Relief of pain resulting from muscle spasm
3. For joints where there are some acute chronic inflammatory processes
4. To improve range of motion and relieve joint stiffness associated with collagen diseases
5. Chronic periarthritis
6. Fibrositis or myofibrositis
7. Epicondylitis
8. Subacute or subchronic bursitis
9. To increase blood flow and improve circulation
10. Chronic inflammatory pelvic diseases[3]

The use of diathermy for therapy or treatment is based upon the absorption characteristics of radiofrequency electromagnetic fields in tissues for therapeutic heating of tissues. It is also based on the physiologic responses produced and the mechanisms by which they are achieved.[2] An elevation of tissue temperature into the range of 40°C. to 45°C. is considered necessary for therapy to be effective.[2, 3]

The use of diathermy as an adjunctive treatment for any other indication is, in the opinion of the agency, an "experimental or investigative use" for which safety and efficacy have not been determined.

Incidentally, in my review of some of the reports on the use of diathermy for hyperthermy, I found that in this experimental use for the treatment of cancers the diathermy devices employed used frequencies of 13.56 megahertz.[4] The Federal Communications Commission (FCC) has assigned definite bands in the range of frequencies and wavelengths to the manufacturers of diathermic equipment for medical use.[5] Such equipment for medical use must meet the frequencies and wavelengths assigned by the FCC. Failure to meet such requirements is a violation of the Federal Food, Drug, and Cosmetic Act, Section 501.

The frequencies assigned for shortwave diathermy are 13.56 megahertz, 27.12 megahertz, and 40.68 megahertz. Most conventional shortwave diathermy devices use the frequency of 27.12 megahertz.[5] The band frequencies assigned for microwave diathermy are 915 megahertz, 2,450 megahertz, 5,850 megahertz, and 18,000 megahertz.[5] The presently available microwave diathermy uses 2,456 megahertz. The 915 megahertz frequency is being used experimentally.[6]

In this context I would like to point out that in reference to the clinical use of hyperthermy, devices which are being used are using frequencies assigned by the FCC to short-wave diathermy and not to microwave diathermy.

Some of you may wonder why I have chosen to refer to drugs and devices rather than just devices. Basically, the reason is to make several points:

1. In terms of drugs, the FDA has, since 1938, been reviewing valid controlled scientific research to substantiate the safe and effective use of drugs for specific indications as the basis for the agency's approval of drugs for use by physicians. Physicians, although occasionally upset by the length of time the agency takes to approve a particular drug, appreciate the assurance of knowing the drug is safe and effective when they prescribe the drug.

2. On the other hand, devices have never been subjected to the same consideration as was required for drugs. In other words, the FDA has never approved any device as safe and effective for its intended use. Most physicians who use medical devices in their practice have mistakenly assumed that the agency has approved such devices simply because the government permits them to be sold.

Equally unfortunately, the valid, controlled, scientific research conducted by experts who are qualified by training, knowledge, and experience to do such research has in most instances not been accomplished.

Most of the evidence to substantiate the safety and efficacy of medical devices is based on subjective clinical impressions of the users. While such impressions are not without a certain historical importance, they fail to meet the usual scientific standard of valid, credible, and reliable evidence.

The FDA, in an effort to correct this long-standing state of affairs, recommended legislation which was enacted as the Medical Device Amendments in May of 1976. These amendments provide additional regulatory authority to determine that medical devices are also safe and effective for their intended uses.

Under the Medical Device Amendments the Advisory Classification Committees have classified diathermy devices, based on their usual and customary use in physical therapy treatments, which depends upon the production of heat in the tissues treated, as Class II. Classification in Class II is based on the assumption that sufficient scientific evidence exists to substantiate the safety and efficacy of diathermy devices for the usual and customary use, and that performance standards—on a generic basis—can be written. The present concept of the Bureau of Medical Devices is that a standard can be written which will prevent hazards related to the use of the device. These hazards are identified by the Advisory Committee in their classification of the devices. The administrative authority over diathermy devices has been transferred from the Bureau of Medical Devices to the Bureau of Radiological Health.

A device which is used medically for a condition which was not considered usual or customary when it was classified is considered to be experimental or investigative (Class III) for that particular new use of indication. To establish the use of the device for that indication will require the accomplishment of all the various requirements necessary to provide valid, controlled scientific research evidence to substantiate the safety and efficacy of the device for the new intended use. Developing such scientific evidence will no longer be simple, conducted in a hit-or-miss fashion by inexperienced or unknowledgeable investigators with little or no knowledge or understanding of scientific methods and principles in the conduct of a scientific study.

In this connection, the agency is proposing certain basic ground rules to be met before the agency will consider any research as acceptable for review when offered as evidence to substantiate the safety and efficacy of the device for its intended use. For those who are familiar with the IND and NDA procedures and requirements for new drugs, similar requirements will be required for medical devices as is set forth in the Classification Procedures Regulations.

It may be useful to review the proposed regulations related to the conduct of scientific studies to be submitted to the FDA:

Non-clinical Laboratories Studies—Good Laboratory Practices Clinical Investigations[7]

Regulations on Obligations of Sponsors and Monitors[8]

Obligations of Clinical Investigators of Regulated Articles, Part V[9]

Standards for Institutional Review Boards for Clinical Investigations, Part IV[10]

Procedures for Investigational Device Exemptions, Part III[11]

Protection of Human Subjects[12]

Classification Procedures[13]

Space does not permit my going into detail on any of the information contained in these proposed regulations.

In conclusion, I would like to quote from an editorial on "Heat as Cancer Therapy" by Drs. J.M. Bull and P.B. Chretien of the National Cancer Institute,[14] with which I am in complete agreement:

> The clinical studies in the literature have lacked controls or have had unacceptable controls. Rationally designed and properly controlled studies are now warranted by the present background of data derived from laboratory studies providing a theoretical basis for hyperthermic therapy and by clinical reports that show the feasibility and efficacy of heat therapy. Emphasis should be given to investigations of the potential of heat to increase the tumor-kill achieved with radiotherapy and chemotherapy, in view of the increasing evidence for the superiority of multimodal therapy over single agents in cancer treatment. Future clinical trials must be designed with precise attention to details of temperature measurement in the tumor and normal tissues and the determination of the effects on all vital functions, as is done in phase I trials of chemotherapeutic agents. Reports of studies that are not conducted on the highest scientific level will be viewed with deserved skepticism by the medical community and will impede the extensive investigations in humans that are needed to define the role of heat in cancer therapy.

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RADIATION AND HYPERTHERMIA*

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CONCEPTS FOR THE ADJUVANT USE OF HYPERTHERMIA WITH RADIATION

CLINICAL hyperthermia can be utilized immediately before, during, or after radiation exposure or at a separate time. Hyperthermia applied to the tumor region prior to, during, or after radiation will sensitize both normal and tumor cells and cause thermal damage. Any changes in the therapeutic ratio obtained by this combination will depend on the differential effects of heating on repair processes of the normal and tumor cells, differences in pH between normal tissue and the tumor, possible alterations in cell kinetics, and the thermal cytotoxic effect.

Normal tissue and tumor hyperthermia in the 41 to 42°C. range used at a separate time from radiation selectively damages cells with a low pH and will not affect radiation repair. Temperatures in the 43 to 45°C. range damages oxygenated normal and tumor cells.

HYPERTHERMIA USED INDEPENDENTLY OF RADIATION

Timing of the hyperthermia should be such that there will be no effect on the radiation response. Current data suggest a time interval of 6 to 24 hours before or after radiation therapy, with a 72-hour interval between thermal exposures to avoid thermal tolerance development. Thermal cytotoxicity depends on individual tissue-thermal tolerance, temperature, duration of exposure, degree of chronic hypoxia, pH, and availability of nutrients. Differential temperatures between the tumor and the normal tissue may be achieved by external heating using microwaves or ultrasound if the tumor blood flow is less than that of normal tissue or if tumor

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metabolism greatly exceeds that of the normal tissue for the same blood flow. With wholebody heating, a differential between tumor and normal tissue temperatures would occur only if either local boosting heating were applied or if tumor metabolism were significantly greater than normal tissue. Duration of heat exposure alters tumor hypoxia and pH. Tumor heating may be associated with decreased tumor pO_2 due to increased metabolism without corresponding increases in blood flow; pH is lowered by increasing anaerobic glycolysis. The selection of appropriate treatment intervals may increase the therapeutic ratio by decreasing developed thermal tolerance of tumor more than normal tissue.

METHODS AND RESULTS

Radiofrequency heating at a frequency of 13.56 MHz., applied to the patient by surface electrodes, has been used by LeVeen et al.[1] and Hahn.[2] LeVeen states that temperatures exceeding 46°C. were achieved in tumors due to decreased blood flow present in the tumors examined. Many treated tumors were exposed at the time of operation. Very limited data on thermometry were reported. Hahn reports[2] that radiofrequency current hyperthermia provides good heat distributions for some tumors because surface electrodes can be shaped to obtain the desired distribution. The method appears to have limitations due to fall-off of heat at depth and from excessive surface heating, the latter of which might be alleviated by controlling the temperature of surface plates by cooling. Sternhagen et al.[3] reported on the use in five patients with recurrent tumors of localized current fields at 500 MHz. using either noninvasive exterior electrodes or implanted needle electrodes. Hyperthermia, using temperatures of 44°C., was applied without radiation therapy and tumor regression was noted. Brenner and Yerushalami[4] reported on six patients treated by simultaneous heating and radiation therapy. At the end of 45 to 60 minutes of heating, heat was applied initially using hot water; later, microwaves were used. Skin temperatures of 42 to 48°C. were reported during microwave heating. The authors reported good tumor regression with an increase in normal skin response.

Johnson et al.[5] reported a pilot study of radiation and hyperthermia to develop a method to obtain the therapeutic ratio for radiation combined with whole body hyperthermia at 41.5 to 42°C. This study used multiple cutaneous metastatic human tumors, treated with a range of radiation doses with higher dose fractions given without heat, while for the low fractions both the tumor and skin were heated to 41.5 to 42°C. Heat was applied using 915 MHz. microwaves. Cooling was obtained by using either liquid dielectric or air surface cooling developed for use with 915 MHz. to improve heat distribution at depth. The pilot study suggests a thermal temperature enhancement ratio for tumors 1.2 to 1.3. The skin scoring data for normal tissue thermal enhancement ratios was inadequate in the pilot study to obtain a therapeutic ratio, but it was apparent that the normal skin response was increased by the addition of postradiation hyperthermia. A cooperative group protocol has been developed by Radiation Therapy Oncology Group to establish a therapeutic ratio for postradiation heating of tumor and skin to 41.5 to 42°C. using a heat period of two hours and three radiation fractions with 72 hours between each fraction to avoid thermal tolerance.

In vivo studies of pigs have been performed by Kowal et al.[6] further to evaluate temperature distributions at depth in tissue. A comparative study of 915 and 434 MHz. was made with and without surface cooling. Surface cooling was performed by passing cool air through pores on the face of an adaptor fitted to the microwave applicator onto the skin of the treatment area. During exposure, skin temperatures of 35.8 to 38.4°C. were maintained. These studies showed that tissue could be heated effectively to a depth of approximately 5 cm. at 434 MHz. without exceeding a temperature of 42.5°C. at any point. With surface cooling, tissue can be heated to a depth of 6.8 cm. and temperature distributions between 2 cm. and 6 cm. maintained within ± 1°C. of 41.5°C. With surface cooling, 434 MHz. produces heating equivalent to 915 MHz. but at an increased depth of 1.5 cm. to 2.0 cm. In another set of experiments the temperature of the cooling air was further reduced initially by passing it over dry ice to obtain skin temperatures of 20 to 22°C. In this case, a constant treatment temperature occurred at 915 MHz. between 1.0 to 5.5 cm. at desired treatment temperatures. This type of cooling did not similarly produce a constant temperature distribution, but a peak was still observed at approximately 3 cm. depth.

Hahn,[2] using an ultrasound technique with surface cooling of the skin, has obtained, in human tumors, temperatures of 43.5°C. at 3 cm. depth with skin temperatures of 41°C. Storm et al.[7] developed a "magnetrode" to heat tumors inductively with a frequency of 13.56 MHz., and states that temperatures of 50°C. can be obtained in tumors located anywhere in the body.

THE USE OF 434 MICROWAVES

Using 434 MHz. microwaves with radiation, Holt[8] reported excellent results. The microwaves were produced by multiple Siemens units with airwave guides arranged to form a tunnel around the patient. Microwaves were administered following radiation for approximately 30 minutes. Tumor and skin temperatures were not monitored, and radiation was supplied in moderate fractions. Hornback,[9] using similar units, reported promising results, and more recently Caldwell, using 434 MHz. units, attempted to make thermal measurements in pigs and in man. Airwave guides caused such interference with metal temperature measurement probes that temperature measurements could only be made by inserting the probes through catheters immediately after the units were switched off. He recorded deep temperatures of 39 to 41.5°C. An *in vitro, in vivo* and clinical study of 434 MHz. hyperthermia is under way to clarify the optimistic clinical reports of 434 MHz. hyperthermia by Holt[8] and Hornback.[9]

To simulate clinical conditions, the effect of microwave hyperthermia on V-79 cell survival is under investigation with and without radiation using microwaves at a measured temperature of 41°C. compared with waterbath controls heated to the same temperature. Preliminary results at 915 MHz. suggest that cell survival can be significantly decreased by high microwave powers and measured temperatures of 41°C. compared with 41°C. waterbath conditions at exposure times of 60 minutes. The magnitude of this "nonthermal" effect is presently being explored at 434 MHz. Thermal distributions for 434 MHz. microwaves have been obtained in pigs both with and without skin cooling. Temperature distributions demonstrated that 434 MHz. is superior to 915 MHz. as detailed above. Clinical thermal distributions in patients are more variable than in swine. Homogenous heating may be maintained in some patients 5 cm. in depth. The clinical study investigates postradiation 434 MHz. hyperthermia with surface cooling on patients with multiple metastases. Radiation doses of 100 rads to 400 rads are used with postradiation hyperthermia of 41°C. to simulate Holt's studies. Response of lesions heated to 41°C. postradiation has generally been superior to the controls, but more patients are required to quantitate the improvement.

BIOLOGICAL RESPONSE TO THERMAL STRESS

Thermal damage of sufficient magnitude will result in cell death in a single cell-survival response analagous to that of ionizing radiation. Mechanisms for cell death from heat are unknown, although denaturation of critical chromosomal proteins, polymerases, etc., and (phase) changes in cell membranes at a supramolecular level may be involved. Such effects may result in genetic damage or damage to membrane transport systems with possible osmotic effects. That thermal inactivation is expressed in a relatively short time compared to cell-cycle time argues for a more immediate and drastic mechanism for damage than is observed with ionizing radiation.

Studies of cell lines have been used to examine the effect of hyperthermia on "normal" and corresponding virally transformed cultures, the latter with a "malignant" potential in host animals. These studies demonstrate no consistent differences in sensitivity of these "normal" and "malignant" systems to hyperthermia. An association may exist between membrane fluidity and sensitivity to thermal insult.[10] Because transformed cells may have more fluid membranes, they may be more susceptible to damage by heat should the cell plasma membrane represent a primary target.

An Arrhenius plot for heat inactivation of cultured mammalian cells suggests two independent mechanisms for cell killing, one above the other below approximately 43°C. This phenomenon corresponds to several observations of alterations in cell response to thermal stress above and below this temperature. Interpretation of data should be viewed in light of two potentially different mechanisms for thermal damage.

One observation which illustrates a change in response around 43°C. is thermal tolerance. At temperatures in excess of 43°C., a negative exponential relation between cell survival and the time of thermal exposure exists similar to the effect of ionizing radiation on cell survival. However, at temperatures below 43°C., still potentially lethal to many cells, a level of survival is attained in an exponential manner with exposure time, beyond which subsequent thermal exposure has little or no effect. These surviving cells have achieved a tolerance to additional thermal challenge. Possibly the mechanism of inactivation at temperatures below 43°C. as demonstrated by an Arrhenius plot is related to the cells' ability to develop tolerance in this same temperature range. The potential ability of a cell to cope with this kind of inactivation may be explained by a "competitive repair" process for this damage or by the existence of a subpopulation of resistant cells. If the latter possibility were correct, the capability for tolerance in these cells might be noninheritable because thermal tolerance is not a permanent phenomenon if cells are returned to 37°C., but disappears after 36 to 72 hours at this temperature. Alternatively, thermal tolerance may express a genetic trait in response to an environmental stimulus, analogous to the production of β-galactosidase by *E. coli* in response to the sugar lactose. However, this expression occurs almost immediately, while the onset of tolerance requires hours. An analogous phenomenon occurs when temperature sensitive, virally transformed cells are returned to 37°C. (the permissive temperature) after a period at 41°C. (the nonpermissive temperature). In this instance, hours are required for the full transformation process, although initial changes in the plasma membrane occur within minutes.[11]

That thermal tolerance is eventually lost after exposed cells are returned to 37°C. becomes of immediate clinical importance in timing subsequent doses of hyperthermia in cancer therapy. Present data suggest that hyperthermia treatment should be spaced by not less than 72 hours to allow for recovery from thermal tolerance. This parameter is not clearly defined and the recovery time for normal and malignant cells may not be the same. The therapeutic ratio could theoretically be improved by selecting the treatment interval if normal cells' thermal tolerance is longer than the tolerance period of the tumor cells.

Studies of hyperthermia of synchronized cultures of cells indicate a cell-cycle effect.[12] Cells in the S phase of the mitotic cycle exhibit an enhanced susceptibility to thermal damage compared to other periods of the cell cycle. This feature is again of clinical interest because the S phase is specifically resistant to damage by x rays, which suggests a valuable complementary association between hyperthermia and x rays in cancer treatment.

In addition to this complementary interaction, hyperthermia exhibits an enhanced ability to damage hypoxic tumor regions. These regions are specifically resistant to x rays because of the absence of oxygen, a radiation sensitizer. When tumor growth removes regions of a tumor to distances exceeding 150 to 200μ from their blood supply, hypoxia and eventual necrosis occur.[13] Under hypoxic conditions cell metabolism relies greatly on anerobic pathways with subsequent lactic acid buildup and reduction in pH. Decrease of a few tenths of a pH unit greatly increases the likelihood that cell death will occur in the presence of a given hyperthermic dose.[14] For these reasons, hypoxic cells resistant to x rays are likely to be more sensitive to hyperthermia.

Tumor hyperthermia applied either at 41.5 to 42°C. or 42.5 to 44.5°C. immediately before radiation may either increase or decrease the radiation response by decreasing or increasing the hypoxic tumor cell fraction. An increase in the radiation response might also be observed in normal tissues which exist in marginal radiobiological hypoxic conditions, providing the increased blood flow is not offset by a corresponding increase in metabolism. Dickson and Suzanger[15] report that 54 of 161 samples obtained from a variety of solid human cancers have significant inhibition of respiration following four hours at 42°C., whereas only three of 74 normal tissue slides showed inhibition of respiration at this temperature, suggesting that increased tumor oxygenation might result. Temperatures above 42°C. progressively decrease the metabolic rate for both tumor and normal tissue. Durand, using an *in vitro* study, reported that temperatures of 41°C. initially increase oxygen utilization, which subsequently is followed by decreased oxygen consumption.[16] Current clinical studies suggest that oxygen tension in normal tissue may increase up to 42°C., but that the response of tumors may be variable depending on the origin of their vascular stroma.

Tissue is a poor conductor of heat, and heat transfer in the body predominately depends on ability of the organism's circulatory systems to remove heat from a given region. Hypoxic and necrotic regions of a tumor with poor circulation would be expected to contain heat more effectively and to reach higher temperatures than well vascularized normal tissue in a given hyperthermic treatment.

Effects of hyperthermia on hypoxic tumor regions through lowered pH, poor heat dissipation, increased oxygenation, and cell-cycle sensitivity individually or in combination project an attractive relation between radiation therapy and hyperthermia. Application of localized hyperthermia during chemotherapy may also yield beneficial results because transport of the chemotherapeutic agent to the tumor relative to normal tissue may be increased.

Another question in either electromagnetically or ultrasonically induced hyperthermia is whether the effect is identical to simple conduction heating or whether additional perturbations are present. Ultrasound cavitation effects are an example of such an influence. Some laboratories claim enhancement of *in vivo* tumor response in the presence of electromagnetic heating relative to water bath heating under comparable thermal conditions.[17] Other studies indicate that *in vitro* microwave hyperthermia may be dissimilar to water bath heating.[18,19] Preliminary data suggest that heating with 915 MHz. microwaves significantly reduces cell survival relative to water bath heating at time intervals in excess of approximately 40 minutes. The difficulty with either *in vivo* or *in vitro* studies of this nature centers on the difficulty in precise thermometry in electromagnetic fields. However, if such observations are substantiated, it may be possible to achieve a temperature bonus, that is, cell survival effects characteristics of 42.5° C. at a fraction of a degree lower temperature.

Whole Body Hyperthermia

Von Ardenne et al.[20] report using water baths to heat patients and have thereby maintained patients at 41.5° C. Although von Ardenne reported the joint use of radiotherapy and hyperthermia, their method cannot be adapted for simultaneous radiotherapy and hyperthermia. Pettigrew et al.[21] use heated anesthetic gases and a surface wax coating to minimize heat loss, a method modified by Larkin et al.,[22] who replaced the wax coating with a plastic sheet heated with a temperature-controlled blanket. The anesthetic method has the disadvantage of requiring full anesthesia and a heating time of 60 to 90 minutes. Other systems include Siemens cabinets using a radiofrequency mattress as an initial boosting procedure. A water-heated sleeping bag has been developed by Atkinson et al.[23] and tested by Bull and her associates. An extracorporal heating system has been developed by Parks. The method is claimed to provide more accurate temperature control and faster heating times.

Although von Ardenne et al.,[20] Pettigrew et al.,[21] and Larkin et al.[22] have frequently employed radiotherapy at some time, there has been no planned controlled study of whole body hyperthermia and radiotherapy. Their clinical investigations suggest that 41.5° to 42° C. hyperthermia causes tumor shrinkage with relief of pain and a general patient improvement.

Complications of Whole Body Hyperthermia

Physiological monitoring of cardiac output by Atkinson et al.[24] shows that cardiac output must increase several times to compensate for the general vasodilation which occurs when patients are heated under slight anesthesia using katamine. Pettigrew et al.[21] report that heart rate and blood pressure remained within tolerable limits so long as the patient was well anesthetized. Pettigrew reports that the use of dry gases has prevented alveolitis. Larkin et al.[22] have reported superficial burns at pressure points from the heated blanket. Unreported experiments in Europe with Siemens cabinets suggest that patients may be heated without the use of anesthesia. Disseminated intravascular coagulation is not infrequently seen in advanced cancer patients undergoing chemotherapy. Ludgate et al.[24] report evidence of disseminated intravascular coagulation in patients with responsive tumors treated with whole body hyperthermia. Three such patients died with platelet counts below 10,000 cmm. and fibrin-fibrogen degradation product levels of 160, 640, and 160 mg./L respectively.

Metastases in Hyperthermia Patients

Dickson and Muckle have reported[25] that the metastatic rate of the VX-2 carcinoma in the rabbit may be increased by hyperthermia, possibly due to an immune process. Yerushalami[26] reports that metastasis was advanced in whole body heated animals, but delayed in animals which received effective local hyperthermia treatment.

Most treated hyperthermia patients have metastases, so no clinical data are available on the effect of either regional or whole body hyperthermia on the metastasis rate in man. Caution should be used before data from animal immune responses are extrapolated to man. Regional hyperthermia will cause vasodilation and possible endothelial damage which might increase the number of circulating tumor cells, but there is no evidence that the human rate of metastases is directly related to the number of circulating tumor cells. Endothelial damage, however, could theoretically increase the ability of tumor cells to seed in the heated site.

Future Prospects for Clinical Hyperthermia

Published results from the use of local clinical hyperthermia suggest that when hyperthermia is applied immediately after radiation, a thermal enhancement ratio of 1.2-1.6 will be obtained.[27] The thermal enhancement ratio depends on the temperature and the length of exposure. Data from the current RTOG trial may determine whether the thermal enhancement ratio for the tumor is greater than that for skin when temperatures are identical. Selection of appropriate time intervals between treatments may improve the therapeutic ratio by utilizing the possibly shortened thermal tolerance period for tumor cells with a low pH.[28] The therapeutic efficacy of heat and radiation will be increased for these tumors where ultrasound, microwave, and interstitial radiofrequency heating have differentially heated the tumor above the temperature of the surrounding tissue. Some tumors have an equal or higher rate of blood flow than the normal tissue, and these tumors may be at a lower temperature than the normal tissue and would not be differently affected by the radiation.

Hyperthermia is currently indicated for patients where differential heating can be obtained, such as metastatic lymph nodes which lie within 5 cm. of the skin's surface. Further improvements in therapeutic efficacy may be possible if radiation sensitizers are added to local hyperthermia.

New heating methods and thermometry are required to treat deep tumors in the thorax and abdomen. LeVeen[1] and Storm[7] both claim ability to heat deep tumors. Hahn[2] and Lele[29] are developing focused ultrasound which may be excellent in heating at depth, providing air cavities are absent.

434 MHz. microwaves may not be sufficient to raise the temperature of a deep tumor above 40°C. Further *in vitro* and *in vivo* work is required to determine whether electromagnetic heating effects from any nonthermal components can be utilized clinically.

Palliation only has resulted from whole body hyperthermia. Safe whole body hyperthermia procedures have been developed. Initial results of whole body hyperthermia and chemotherapeutic agents warn of possible toxicities which may occur. The use of local hyperthermia with chemotherapy for multiple superficial lesions will determine whether in fact the action of the two methods are additive or synergistic. If specific types of superficial tumors respond to combined superficial hyperthermia and chemotherapy, it would appear appropriate to proceed with whole body hyperthermia and the same chemotherapy provided that toxicity tests have been performed in large animals and phase I human studies. The current rapid development in equipment and increasing clinical experience should determine the types and sites of clinical tumors which would benefit from routine clinical hyperthermia.

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DIAGNOSTIC AND THERAPEUTIC USES OF RADIOFREQUENCY FIELDS*

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NEAR the beginning of the 20th century it was possible to purchase a variety of "electrical" appliances designed to alleviate human ills ranging from "female complaints" to cancer. So many of these appliances simply did not work that very healthy skepticism tended to obscure serious experiments by such workers as D'Arsonval or Tesla[1] using radiofrequency induction fields to produce hyperthermia, which they thought might be useful in the treatment of some carcinomas or serious infections. Unfortunately, most of these experiments were performed with only rudimentary knowledge of the field distributions in their subjects and with an even more rudimentary knowledge of the nature of human thermal exchange mechanisms.

Partly because of early failures, virtually the only use of radiofrequency fields in treatment of human ills was to generate tissue heat to relieve muscle spasm and attendant relief of pain by use of diathermy until about 20 years ago. It appears that even this use was based on analogy with known actions of hot packs and baths rather than on the results of serious investigation other than for effectiveness. Thermal distributions for many such devices were determined by Lehman's group quite recently.[2,3,4]

Use of radiofrequency fields in controlling local cell-mediated immune responses has some merit. Liburdy[5] has shown that the relative immediacy of radiofrequency-induced hyperthermia can cause sudden elevations in circulating plasma glucocorticoids much more drastic than those achieved by warm air or water immersion. This was directly related to the delayed hypersensitivity reaction tested with response to immunogen injection in

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the foot pad of properly prepared mice. Further, he also demonstrated that the lymphopenia associated with such action could be maintained for several days by repeated applications of radiofrequency fields twice a day. The nature of this kind of response in more cortisone-resistant species[6] is not accurately known, but results found by Prince et al.[7] indicate that at least part of the response can be elicited in primates. Lovely et al.[8] used a system developed by Guy[9] to demonstrate conclusively that field application directly to cultured lymphocytes in the amplitude range used by Liburdy or Prince could elicit no observable response at all. This finding is in contrast to the earlier findings of Mickey,[10] who applied somewhat similar fields, but allowed development of severe hyperthermia with cytolytic effects on isolated cells.

It thus appears that many of the effects on the circulating blood elements that have been associated with radiofrequency fields of moderate amplitudes (up to 15 W/kg. absorbed power) are related to adrenal corticoids and release of ACTH from the pituitary. In this respect, radiofrequency fields act as a classic stressor differing from other forms of hyperthermia in the rapidity with which tissue-level hyperthermia can be induced. There appears no information at the moment as to the nature of the signal that causes ACTH release and little information as to the distribution of local hyperthermia that might result in such a release.

Uses of radiofrequency-induced hyperthermia in the treatment of tumors are reviewed elsewhere[11] and relative sensitivities of individual portions of the cell cycle are there reviewed.

When much higher amplitude fields are utilized to study isolated tumor cells, followed by assay for invasiveness and tumor growth in mice, a very different set of events emerges. Riley et al.[12] found that exposing cultured cells to temperatures of 42°C. with simultaneously applied 33 mHz. fields produced colonies which would initiate a tumor, but at the 13th to 14th day tumors spontaneously regressed. Controls from simultaneously run cultures exposed to the same temperature were not very different from control assays for tumor growth. This effect could not be produced at 450 mHz., but could be produced at 33 mHz.[12,13] Lower frequencies have not yet been utilized, and whether pulsed fields at 33 mHz. would be effective is not yet known. Dr. Riley has performed many experiments at comparatively low field amplitudes and demonstrated no effect. He has been able to produce a similar but diminished effect at 38°C. When compared to the specificity of nuclear magnetic resonance techniques and the possibility of a surface alteration of tumor cells as indicated by Bramwell and Harris,[14] these findings could be clinically extremely significant.

Another system requiring both a thermal and a field component was described by Moody et al.,[15] where normally resistant bacteria were made susceptible to infection with bacteriophage T5 by field application. The bacteriophage itself, however, demonstrated an extreme sensitivity to the applied field, so that treatment of the combined system suppressed phage infection, even at low temperatures.

These two sets of examples have been selected to show that high amplitude fields appropriate to a clinical setting with adequate control have characteristics only dimly understood at the moment and apparently distinct from the types of considerations used at the much lower fields (four orders of magnitude at least) one might find in the general environment.

Possibly the most serious study of the effects of low frequency fields on biological systems was initiated many years ago by Becker,[16] who pointed out the effects that could be obtained from low intensity fields on bone structure, fracture healing, and wound healing. Becker's work has been extended to use of a small induction coil to aid fracture healing.[17] Apparently this process may also be important in alveolar bone.[18] The precise mechanisms by which such field effects can be propagated in time as a relatively permanent biological alteration are open to question, but they certainly are real.

For many years it was thought that imaging internal human structures by means of radiowaves was both theoretically and practically impossible because of the relation of wavelength to resolution required in comparison to that achievable by use of x rays. Indeed, comments made during a 1973 NATO conference on "the inverse scattering problem" indicated a near total lack of belief in any near term solution adequate for imaging.[19] During the past five years this kind of thought has undergone considerable revision, and some practical demonstrations of such imaging have already been made.

One reason for a perception of possible use of inverse scattering has been a series of "small steps" in the theoretical foundations of scattering theory since Bojarski's[20,21] original work. Weston and Krueger[22] showed that a one-dimensional solution of object form or wavefront construction was possible, but a possible three-dimensional solution did not occur until much later, when Krueger[23] developed a way to handle multiple dielectric scattering in an inhomogenous matrix which allowed dielectric discontinuities. Thus, it now appears that there are representative solutions for one, two, and three-dimensional space—an achievement of no mean magnitude in itself. This achievement has led to others, as evidenced by a recent symposium on inverse scattering methodology applied to natural resource and target descriptions.[24] Amazingly, medical uses were not represented at the symposium.

Probably the earliest perception to allow serious consideration of radiofrequency imaging was a series of reports by Bojarski,[20] who defined the edges of regular geometric objects by applications of Fourier transforms of amplitude functions of microwave radiation scattered from illuminated objects and demonstrated that object and wave properties were a transform pair. More recently, Bussey[25] and Bussey and Richmond[26] have shown that the assumption of a geometry and complete definition of scattered fields allowed reconstruction of a plane wave in two dimensions. Bussey demonstrated a quantitative lower limit to sampled scattered wave which would allow such a reconstruction, placing a lower bound on the amount of field sampling required. While this two-dimensional solution was explicitly aimed at wavefront reconstruction, its success was due to the assumption of a geometry, and implies a relation between the precision of the assumed geometry and the extent and precision required for analysis of scattered waves in order to arrive at a geometric definition. Unfortunately, the work has not yet proceeded to this point.

Weston[27] and Weston and Krueger[22] examined the inverse problem and mathematically arrived at a solution in one dimension. Successful continuation to conducting spheres by Ahluwahlia and Boerner[28] soon followed. Krueger[23,29] was later able to reduce that problem to a single Gelfan-Levitan integral equation, and more recently extended those results to three-dimensions, including multiple discontinuities. Further developments have occurred in a recent symposium on Inverse Problems,[24] especially in a paper by W.R. Stone[30] applying the Bojarski "exact"[21] inverse scattering to a mapping problem. From this kind of data one can conclude that the mathematical basis for imaging with variants of inverse scattering is sufficiently well developed to allow practical implementation.

One of the earliest publications showing physiological perturbations of a well defined radiofrequency applicator signal, implying the biological reality of inverse scattering, was by Johnson and Guy,[31] who showed that reflection amplitude excursions correlatable with cardiac motions were obtainable from the human chest. Guy[32-34] has also performed many experiments showing that internal field distribution in models of humans depended on the external field frequency and impedance, but that frequencies below geometric resonance on a ground plane (about 40 mHz. for 70 kg. man) caused very stable field distributions as measured thermographically. Unfortunately, thermographic distributions in whole animals have been measured only minimally, so that only a small amount of field-distribution information is available for nonhomogeneous biological structures.

In our laboratory, studies on thoracic reflectometry have been extended by Michael Millner using an S parameter network analyzer and a dedicated computer to develop a method for noninvasive determination of cardiac stroke volume and output. The eventual aim of Millner's research is radiofrequency imaging, and we are using the heart as an internal "signal generator" as one step in technique development. We have utilized as a model system a balloon immersed in saline with displacement volume measured in a standpipe. In this particular system both the capacitive phase shift and decrease in reflection amplitude are proportional to volume because of the capacitance of the strip of saline between the balloon and the external surface. The total loss of conducted electrical signal, measured as "in phase" reflected signal, is dependent on the electrical properties of the balloon contents, hence our use of these signals in determination of volume.

Millner has repeated earlier measurements by Johnson and Guy[31] and Frazer[35] of the human chest. Phase-amplitude alterations are those expected from alterations of the anterior posterior cardiac position, while reflection-amplitude measurements reflect losses probably related to the filling curve of the heart plus filling and emptying curves of the blood distribution in the lung. The applicators used in these studies are standard ring inductors and dipoles that are also sensitive to capacitance change. Mutual inductance measurements between transmitter and receiver ring can be made, allowing use of lower frequencies than had been used previously. Analysis of loss as a function of phase angle and distance into the chest indicates that imaging is possible in the ideal future.

Larsen and Jacobi[36] utilized a somewhat different scheme to perform what they call "interrogation" of dielectric models at wavelengths short in comparison to the object being interrogated. They examined scattering from the object, and in a second paper[37] examine differences in transmission time produced by differences in dielectric constant in several model objects. This general technique embodies some of the principles of antenna scanning described by Wacker,[38] who has shown the importance of properly constructed geometric coordinates relative to the shape of the transmitting elements, a problem now being addressed in the context of Larsen and Jacobi's imaging systems.

Following a suggestion of Süsskind,[39] Pedersen et al.[40] have investigated a variety of microwave techniques in exploring the development of pulmonary edema. Iskander et al.[41] continued this work and showed that model systems consisting of isolated lungs, phantom models, and experimental animals all completely validate Pedersen's earlier findings that analyzable changes in thoracic impedance at microwave frequencies are brought about by increased hydration as expected from changes in pulmonary dielectric constant and consequent alterations in scattering.

While the methodology cannot be considered ready for clinical practice at the present moment, it has progressed to experimental measurement in humans at the University of Utah.

A specific form of radiofrequency imaging has been used experimentally since about 1971. For a description of magnetic resonance spectroscopies, see Herak.[42] Nuclear magnetic resonance (NMR) depends on the alignment of atomic species along magnetic fields, precessing at a frequency determined by the type of atom and the magnetic field strength. By placing a body in a known magnetic field gradient and using exactly known frequencies, concentration of nuclei at specific points in the body can be determined. The rate at which nuclei leave this ordered state is also characteristic of the atom and its chemical environment, and this relaxation has also been used as an imaging modality.[43-47] Indeed, Damadian[48] used this modality to investigate a large variety of tumors and found that hydrogen relaxation could be correlated with the presence of invasive tumors.

Nuclei utilized for imaging have been primarily H^1 protons, so that resultant anatomical cross sections published by Damadian, Lauterbur,[49] Andrew,[50] Mansfield et al.,[51,52] and others are primarily of water. Radiofrequencies utilized have been in the 3 to 10 mHz. range, allowing analysis of H^1 protons in magnetic fields of 500 oersteds. Bottomley and Andrew[53] have analyzed field distributions at those frequencies and their relative ability to induce local hyperthermia. These authors find that little if any safety problems exist in such procedures, although aberrancies in field distribution cause some problems in the resolution possible with present techniques. The magnitude of this problem is more graphically illustrated in the descriptions by Guy et al.[32-34] of field distributions in man and several models using thermographic sectioning techniques. It seems apparent, then, that even the NMR imaging techniques will ultimately use some of the inverse scattering methodologies to achieve geometric resolutions better than the few millimeters attainable at present.

Each of the groups studying imaging modalities of nuclear magnetic resonance (NMR) has adopted slightly different methodologies. Damadian's group uses FONAR (Field Focussing Nuclear Magnetic Resonance), which depends both on magnetic field distribution and on nuclear decay rates. Lauterbur has chosen the term zeugmatoscopy (to join together magnetic and radiofrequency fields). Hinshaw,[54] working with Andrew at Nottingham, published the "sensitive point" method, and later this became the "multiple sensitive point method."[50] In all, there are said to be at least eight methodologies at present without a really professional analysis of the distinctions between them.

While imaging of H^1 protons has been used primarily up to the present time, other nuclei (Na, K, Ca, C,[13] P^{31} for instance) could conceivably be used for chemical mapping if some of the present considerable problems in field interaction and equipment "sensitivity" could be worked out. Damadian[43] has repeatedly stated his interest in forming a "chemical map" of humans as a much more sophisticated noninvasive diagnostic aid than is available anywhere at the present time. An example of the sophistication such a chemical map could achieve was shown by Chances' group[55] in a very elegant demonstration of the alterations of phosphorous-containing compounds of the brain during simple hypoxia as determined with nuclear magnetic resonance of P^{31} in the intact animal completely noninvasively. Chance found it possible to determine adenosine triphosphate, adenosine diphosphate, adenosine monophosphate, creatine phosphate, and inorganic phosphate and their changes in concentration during brief exposure to a nitrogen atmosphere. Undoubtedly, other compounds could be analyzed using different relaxation times and phase angles than those used for the high energy phosphorous compounds reported. It will undoubtedly be some time before the knotty engineering problems involved in reducing such signals to Damadian's map in a short sampling interval will be achieved, but even superficial consideration of the rewards for such an effort would seem to make it eminently worthwhile. Consider, for instance, the ability to determine the distribution of cellular events in suspected cerebrovascular accidents or cardiac events in suspected coronary occlusion, to mention only two possible uses.

To use a chemical map efficiently in diagnosis of invasive tumors, some chemical peculiarity of those cells must be evident. Damadian[48] found one such set of peculiarities in the proton relaxation times of defined tumors as compared to normal tissues. In use as part of an imaging algorithm it may be necessary to make several different kinds of relaxation of different chemical nuclei because different tissue relaxation times may obscure the tumor signal in any one analysis.

Such a chemical peculiarity is advocated by Bramwell and Harris,[14] who have found a 100,000 molecular weight glycoprotein in tumor cells that is suppressed by fusion with normal cells and later resegregates to form invasive cells. The authors are struck by the similarity of this glycoprotein to the insulin receptor protein in mass and low isoelectric point (pH 4.0) when compared to the isolated receptor of Jacobs et al.[56] While the chemical ''peculiarity'' associated with the molecule has not yet been well worked out, its lectin-binding capacity and the possibility of nuclear magnetic resonance related chemical signal in addition to the ones found by Damadian (or perhaps underlying them) certainly offer diagnostic possibilities.

In sum, the complete realization of potentialities in nuclear magnetic resonance imaging depends to some extent on use of principles of near field scanning and inverse scattering which are reasonably well developed theoretically but still require considerable effort to produce medically useful equipment. While rather optimistic marketing claims have been made, it appears that locally constructed instrumentation will be necessary for at least the next five years, and that a considerable number of refinements will take place during that time. A full scale effort by a serious funding agency is required.

Other forms of imaging, using variants of scattering analysis or time delay reflectometry are attractive prospects, theoretically well based, but further from realization. Solutions to similar rather knotty problems of field distribution will be required for successful deep tumor treatment.

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POTENTIAL INTERFERENCE WITH MEDICAL ELECTRONIC DEVICES*

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NONIONIZING electromagnetic radiation can adversely affect diagnostic and therapeutic medical devices that process bioelectric signals, transducer electrical signals, or radio telemetered signals. Frequencies of interfering radiation range from below 50 Hz. to beyond one gigahertz. This electronic "smog" may be sensed directly by the affected device; it may be demodulated and sensed. These effects are mitigated by limiting the level of emissions where medical devices are likely to be used and by decreasing the susceptibility of devices. An implantable artificial cardiac pacemaker is a well-known example of a device that can be sensitive to interference because of its widespread use and the publicly perceived dependence of pacemaker patients.

The bad news about the potential electromagnetic interference with medical electronic devices is that these devices appear to be more sensitive to electromagnetic waves than organisms. The good news is that the effects of electromagnetic interference are more easily detected and it is possible to make devices less sensitive to it.

Let us consider the mechanism of interference. The accompanying figure shows the general mechanism for interference entering a medical electronic device. The most susceptible types of devices are those that utilize low level electrical signals to gather diagnostic information or to perform a therapeutic function. Bioelectric sources, transducers, telemetry signals, and low level recordings are four areas where electromagnetic interference can distort essential device function. Examples of various devices and their effects are shown in Table I. With any type of medical device, the primary mechanism encountered is noise, distortion, and loss

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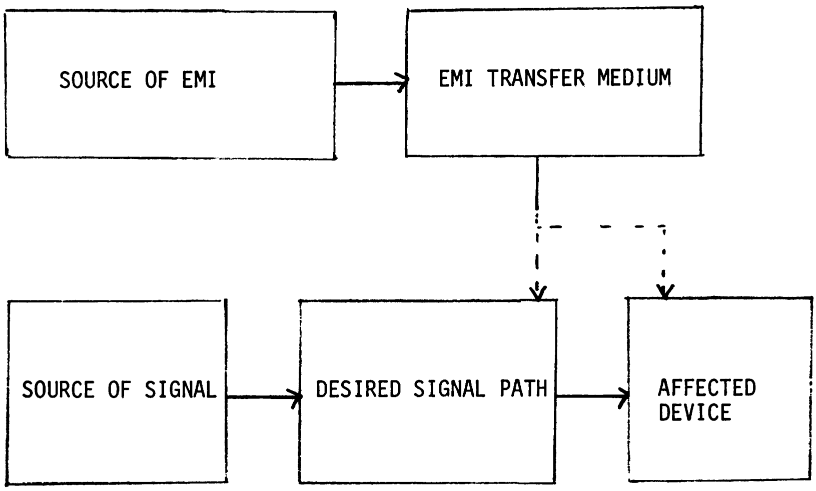

General mechanism for interference entering a medical electronic device

of signal. In therapeutic devices function is lost because the signal is used to make therapeutic decisions. Based upon many reports of effects on medical devices, I would rank sources in decreasing order of importance as shown in Table II. The interference can be transferred through the subject, power lines, space, or other instruments.

Electrosurgical units use radiofrequency energy to cut and to control bleeding. The large amounts of energy they emit effectively prevent simultaneous electrocardiography. Ruggera and Segerson[1] measured electromagnetic fields as high as 1,000 v. per centimeter at 16 cm. from the operating probe. These signals diminish greatly with distance. Bochenko[2] investigated energy flow and found that power is drawn from an outlet to produce cutting and coagulation within the patient's tissues. Unfortunately, some of the radiofrequency energy reaches other medical devices through the patient, by power lines, and by radiation. Careful design can reduce the level of radiated and conducted energy.

Diathermy provides therapeutic heat to subcutaneous tissues,[3] but has been associated with dangerous interference and heating of cardiac pacemakers.[4] In a reported incident, an external pacemaker was inhibited by a fluoroscope.[5] Much of the interference is near field. In one case the magnetic field from an audible alarm speaker on a blood-pressure monitor activated a magnetic reed switch on a ventilator, and disrupted the normal ventilation cycle.[6]

TABLE I. SOURCES OF ELECTROMAGNETIC INTERFERENCE

Rank	*Description*	*Example(s)*
Decreasing importance		
1	Other medical devices	Electrosurgical units diathermy
2	Power lines	Device cords, etc.
3	General electric equipment	Motors, fluorescent lights
4	Communications	TV, FM, CB
5	Natural	Lightning, solar flares

Power lines interference is quite common. Huhta et al.[7] discuss how line frequency noise can enter an electrocardiograph and how to mitigate these effects. Kostinsky[8] reported that certain external pacemakers are sensitive to power-line interference conducted to the device by touching its front panel. Powered limb prostheses can be commanded by low level electromyographic signals. These signals can be easily overwhelmed by external interference.[9,10] It is also suspected that high tension power lines can disrupt normal operation of implanted cardiac pacemakers.[11]

Interference from electric equipment can take many forms. Electric motor brushes, antitheft devices, automotive ignition systems, and microwave ovens are potential offenders. Even an electric watch can interfere with a medical device.[12]

Communications can also interfere with medical device operation. Emergency mobile communication systems can require placement of transmitters close to sensitive electromedical equipment. An indirect mechanism was reported in which the sweep coil of a television set distorted an electrocardiogram.[13] The Environmental Protection Agency has investigated a case where an electronic thermometer was sensitive to a nearby FM station.[14] Vreeland et al.[15] studied the effects of broadcast stations upon cardiac pacemakers and recommended a susceptibility limit of 1 v./m. average and 1.5 v./m. peak.

Lightning is the significant source of natural interference. Because it is intermittent and intense, lightning is more of a problem from damage it can cause through power-line surges than for occasional interference.

Because of the problems of electromagnetic interference, the Bureau of Medical Devices is developing guidelines for medical device susceptibility. To define the problem, Jenkins et al.[16] surveyed radiation levels

TABLE II. TYPES AND EXAMPLES OF EMI SUSCEPTIBLE SIGNALS USED IN MEDICAL EQUIPMENT

Signal type	Examples of susceptible devices (effect) Diagnostic	Therapeutic
Electro-physiologic	Electrocardiograph (noise, distortion)	R-Wave inhibitable Pacemaker (inhibition, competitive pacing)
Transducer	Blood pressure (noise, distortion)	Respirator (loss of control)
Telemetered	ECG ward monitor	Programmable pacemaker ("phantom" programming)
Recorder	Heart rhythm monitor (noise, distortion, and loss of signal)	

present in various medical facilities, and Hoff[17] took this study one step further by suggesting standards and explaining their rationale. The Food and Drug Administration expects to publish the standard as a formal guideline.

Pacemakers are the devices most frequently associated with dangers from electromagnetic interference. Actual or potential pacemaker interference has been reported from antitheft devices, microwave ovens, microwave search radars, CB radios, electric motors, ignition systems, and arc welders. Concern about the health hazards from electromagnetic interference with pacemakers is only partially justified because few pacemaker patients are totally dependent upon their pacemakers.

Pacemakers work by providing an electrical stimulating pulse directly to the heart about 70 times per minute. Pacemakers are generally installed just below the skin with a lead directed to the heart through a vein. In a minority of cases the lead may be sutured to the epicardium or may be screwed into the epicardium using a corkscrew electrode.

Interference can enter directly into a pacemaker circuit, but interference is more likely to enter by way of the pacemaker lead which can act as an antenna. In terms of interference susceptibility, there are two principal types of pacemaker electrode leads. The bipolar lead places both the stimulating electrode and the electrical return electrodes on or in the heart. These are less susceptible because the spacing of the electrodes and, thus, the effective antenna length are shorter, and the electrodes are better shielded by the body.

In the case of the unipolar lead, the pacemaker case acts as the return electrode. Here the spacing between the leads is much greater, the effective antenna length is longer, and therefore the susceptibility is greater. Because unipolar systems possess some medical advantages, they are used frequently.

Several different types of pacemakers are in use. About 90% of pacers are of the demand type, capable of sensing the R-wave portion of the individual's interior electrocardiogram through the pacing lead. When the pacemaker senses the R-wave which coincides with each heartbeat, it withholds or inhibits the output pulse. Unfortunately, some types of electromagnetic interference can appear to the pacemaker as a series of R-waves and thus falsely inhibit the pacemaker. Because these pacemakers are usually implanted in people who have some sort of underlying bradyarrhythmia, inhibition of the pacemaker would probably cause the patient's slower underlying rhythm to take over. If this happens, the symptoms the patient had before pacemaker implantation would return: dizziness, fainting, and nausea. If inhibition occurs in a totally dependent patient, death could ensue.

Because radiofrequency interference with cardiac pacemakers has been identified as a potential hazard for many years, pacemakers now incorporate metallic enclosures, radiofrequency blocking filters, and band-pass filters to mitigate against this hazard. In addition, since many potential sources of electromagnetic interference lie within the band pass limits (about 6 to 80 Hz.), the pacemaker incorporates a feature that converts the pacemaker to a fixed rate mode when continuous interference is present. In this mode the pacemaker emits pulses regardless of cardiac activity. This, in turn, results in less efficient competitive pacing if natural pacing is also present. This is generally considered less dangerous than inhibition because the patient receives continuous cardiac support.

To investigate a reported incident concerning a pacemaker and a CB radio, the Federal Communications Commission and the Food and Drug Administration's Bureau of Medical Devices recently conducted tests at the Commission's laboratory in Laurel, Md. We placed the pacemaker in a saline solution in a foam tank and irradiated it at 27 MHz. at 3 v. per meter. Three modulation schemes were used. Forty millisecond bursts were transmitted at a rate of two pulses per second to attempt to inhibit the pacemaker. Voice-modulated single side-band was also used to attempt inhibition. In other test runs continuous wave modulation was applied to attempt to revert the pacemaker to fixed-rate operation. Although we did not cause any discrete effects, we did note a shift in pacemaker threshold. This may indicate that the pacemaker would be inhibited at much higher field intensities.

Finally, work done at the Georgia Institute of Technology since 1973 shows that while great variability exists in the level of susceptibility from pacemaker to pacemaker, it does appear that more recent pacemakers are less susceptible to interference.[18]

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GENERAL DISCUSSION: SESSION IV*

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DR. HERBERT POLLACK: Before opening the general discussion, Dr. Gandhi will discuss some recent developments in electromagnetic applicators for local and whole body hyperthermia.

DR. OM P. GANDHI (University of Utah): I shall discuss two aspects: first, the development of lower frequency broad band applicators to obtain deeper heating of tissues and, second, preliminary development of an electromagnetic applicator for whole body hyperthermia. In spite of widespread use of 2,450 and 915 MHz electromagnetic energy to produce local hyperthermia, depths of penetration are extremely limited at these frequencies. At high microwave frequencies a substantial fraction of the total energy is absorbed at the skin. At lower frequencies, particularly frequencies of the order of 300-500 MHz., there is significant reduction in energy deposition in the skin and most of the energy is thus imparted to inlying tissue. This is also apparent when one considers depths of penetration at various frequencies reported in Johnson and Guy's article. Local hyperthermia applicators at lower frequencies are therefore needed. Some applicators developed by Bio-Systems Design of Salt Lake City are described in Table I. The VSWR less than two means 90% transfer efficiency over a wide range of 200 to 550 MHz. Dimensions of the various applicators can be as low as required. In fact, they have fabricated a wide variety of applicators with dimensions as low as two inches by one and a half inches to six and one half by four inches. An interesting and very wide band applicator is that given in D (Table I). The measured VSWR for this parallel-type applicator is shown in the figure. Part of the problem in the past was that at lower frequencies the typical wave guide type

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TABLE I. SOME TYPICAL APPLICATORS FOR LOCAL HYPERTHERMIA

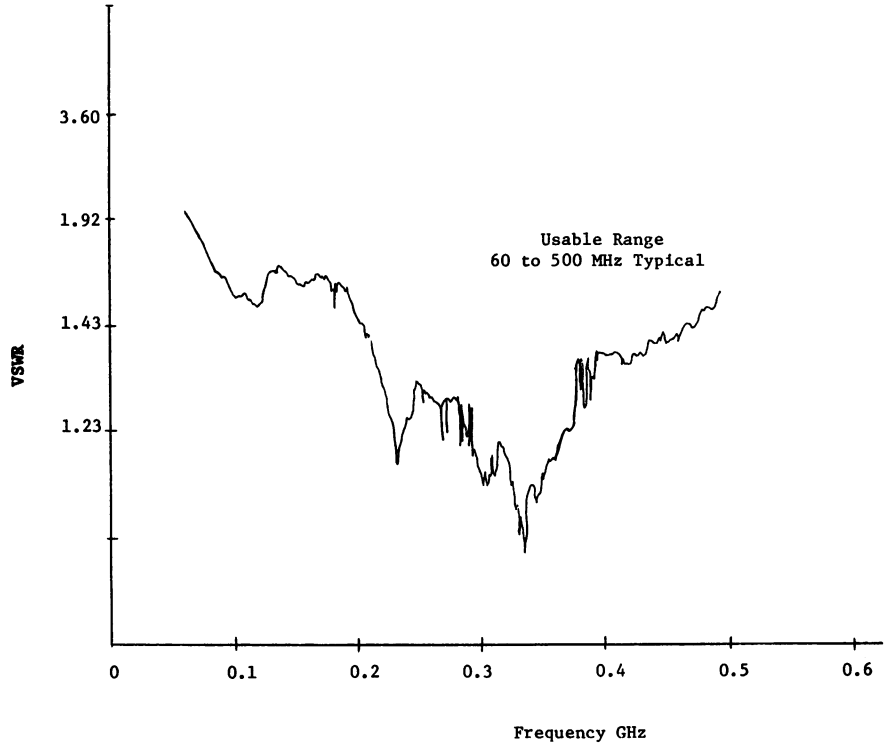
	Aperture dimensions
Dielectric loaded waveguides	
A. 200-550 MHz. VSWR ≤ 2 (10 dB return loss)	4″ × 5″
B. 650-1500 MHz. VSWR ≤ 2	2″ × 1.5″
Shaped field applicator for uniform heating	
C. 400-600 MHz. VSWR ≤ 2	6.5″ × 4″
Broadband parallel-plate applicator	
D. 60-500 MHz. VSWR ≤ 2	4″ × 5″

Each of the above applicators can, of course, be scaled up or down for a different frequency band of operation.

applicators were too big to be of much use, a problem alleviated in parallel-plate type applicators which can be made with aperture dimensions as small as desired.

Salient features of the BSD-1000 system that the Bio-Systems Design markets are shown in Table II. Important characteristics of the system are: 50 to 1,000 MHz. (expandable to higher frequencies), frequency stability, microprocessor control of up to 100 watt output, power stability, and the transfer efficiency of better than 90%. They have designed several applicators and are willing to design others to physician specifications for special applications. The biological feedback is provided by up to six nonperturbing temperature probes, each with a diameter of about 1 mm. to 1.5 mm. We hope that the semiconductor band gap type temperature probe under development at the University of Utah will be available before long and will be useful for such applications. This probe has a tip diameter less than 1 mm.

Low frequencies on the order of 75-150 MHz. offer the advantage of heating from the inside out rather than by blood-mediated outside-in heating methods presently employed. Another advantage of an electromagnetic whole body hyperthermia system is that one may be able to heat the patient to temperatures of the order of 106-108°F. in about half an hour, rather than two hours as at present. We do, however, need applicators capable of relatively uniform electromagnetic energy deposition (within about 2:1). Although my physician friends say that perhaps there is



Wide band applicator-human abdominal match 14 by 14 cm. heating area typical

not that much need for uniform heating, I think that there is some merit in not loading the hemodynamic system more than it ought to be and relatively uniform rates of energy deposition should help in that regard. An applicator we have looked at, with a reduced scale biological-phantom-filled model, is a parallel-plate end-terminated applicator that yields fairly uniform rates of energy deposition. Work presently continues to improve the uniformity and energy transfer efficiency of such applicators.

MR. EDWARD HUNT (Walter Reed Army Institute of Research): I have been impressed by the relation between research in designing applications and feedback to the science and biology of microwaves from use of these applications. This is an extremely important transfer of information between applications research and basic science.

My second comment relates to microwave tomography, having to do with the properties of the interrogating energy. With microwaves the

TABLE II. SALIENT FEATURES OF THE BIO-SYSTEMS DESIGN, INC., HYPERTHERMIA SYSTEM

Microwave	
Frequency range	50-1,000 MHz.
Expandable to	10-2,500 MHz.
Frequency stability	0.1 MHz. (Microprocessor controlled)
RF power	85-100 W
Power stability	0.5 W (Microprocessor controlled)
Power transfer efficiency:	Up to 95%
Number of available applicators	7 (to cover the 50-1,000 MHz. band, and also allow a variety of aperture dimensions from 4 x 5 cm. to 10 x 15 cm.)
Reflected power	Less than 10% Less than 2% with the autotuner
Biological feedback	
Controlling the microwave output by real-time temperature data from up to 16 nonperturbing probes	
Accuracy	0.1°C.
Temperature sample rate	0.5 Hz.
Loop response	2 seconds
Black-and-white and color video temperature display	

energy is transmitted, scattered, reflected, and so forth with respect to species of molecules and characteristics of structure very closely related to the physiological functions of those molecules and structures. It makes biological sense to use it as an interrogating source. This contrasts, for example, to ultrasound tomography, which depends primarily on the tissues' acoustic properties or with x-ray tomography which depends on distributions of the atomic species within molecules and tissues.

DR. JAMES FRAZER: On May 14, 1979, at the University of Maryland, Dr. Prohousky of Purdue University will discuss acoustic transmission through important biomolecules, and we have been missing a bet in acoustic spectroscopy for a long time so far as macromolecules are concerned. However, the rest of Mr. Hunt's comments are, of course, true. One can now noninvasively determine functional specificities using microwaves that one simply cannot obtain any other way. About three weeks ago, HEW Secretary Joseph Califano announced an assault on the use of medical x rays because of possible damage to the patient. Whether or not such damage exists is beside the point. The relative risk is, I think, far less with microwaves than with ionizing radiation. That alone should justify much further development of this particular field. The possibilities are almost limitless.

MR. RICHARD REIS: Dr. Pollack mentioned the longevity of pacemakers. Pacemakers now last five to 10 years because of lithium batteries. Intrinsic device reliability has been a much more significant problem in pacemakers than electromagnetic interference and it is important to put it in that perspective.

So far as the observed effect of interference during our experiments goes, we were using a walkie-talkie to transmit from our receiving station, where we were monitoring the pacemaker that we were studying, back to the transmitting station. We could not monitor while we were using the walkie-talkie because it interfered with our sensitive instruments.

I ask Dr. Pollack to give a little bit of background on the Russian response to our queries on irradiation of the American embassy. I imagine that we asked them why they were irradiating us and so forth, especially in view of their lower standards.

DR. HERBERT POLLACK: In the first place, they have tentatively increased the standard to $5\mu W$, which automatically puts all the maximum chancellery radiation before June of 1975 in the safe level. This is a very important political step as well as a scientific one. Why they were doing it they have never told us. That is one of the secrets that they maintain.

MR. ALAN DROSIN: Mr. Reis, I had the impression that the shielding problem was more serious than you seemed to indicate. Did I misinterpret what you said?

MR. RICHARD REIS: The overall reliability of the pacemaker depends more on other phenomena. There are two critical problems. The first is the unreliability of the battery, specifically the mercury battery, which usually fails in 18 months to two years. The second is the intrusion of moisture into the pacemaker's electronic components. The mercury battery was being improved and it seemed that it would be considerably better, but then the lithium battery came along and it is far better than the mercury battery could be. The other aspect was improved by making the pacemakers hermetically sealed, which had the added benefit of making them slightly less permeable to electromagnetic radiation.

MR. DROSIN: Are you now fairly satisfied with that?

MR. REIS: We still have to exercise some caution in that area. Pacemakers are inherently susceptible to electromagnetic effects, as is any sensitive electronic instrument, particularly in the very low frequency area, where they are intended to be sensitive. The input amplifier of the pacemaker is sensitive from 6 to 80 Hz. Obviously, they will be sensitive to low frequency electromagnetic interference.

DR. NORMAN SIMON (Mt. Sinai School of Medicine): I would like to ask Dr. Frazer a question about his remarkable talk on frontiers in energy. First, the effect of microwave radiation at nonthermal levels does not seem to have been explained as certain at this meeting, whether it is because we do not measure the temperature gradients at nonthermal levels or because it is discrete microscopic temperature and the biological effects appear at higher temperatures, I am not sure. My question pertains to your very interesting exposition of nuclear magnetic resonant image, the cross-section of the chest. Is a thermal effect to be considered even at the energy levels at the same resonance or is it likely that there will not be detectable thermal increases?

DR. JAMES W. FRAZER: There seems little possibility both to get a thermal event and to form a nuclear magnetic resonance image. With electron paramagnetic resonance, however, the frequency is high enough that one could intentionally turn up the power to produce tissue inactivating thermal pulses in a very tightly localized region. That would be a matter of intense localized treatment. One would use nuclear magnetic resonance as a locator, and electron/paramagnetic resonance as a treatment modality. One would, of course, have to be skilled in the use of the apparatus. It is not a job for amateurs.

DR. RUSSELL L. CARPENTER (Bureau of Radiological Health): Dr. Johnson, in applying microwaves locally for local heating, has any incident been made of dielectric lenses which focus the microwave?

DR. RICHARD JOHNSON: Not that I know of. It has certainly been thought of, but I don't know of any studies. Maybe Dr. Gandhi knows.

DR. OM P. GANDHI: No,. not to a large extent. I have seen some reference to this, but not in the context of hyperthermia.

DR. JOHNSON: Dr. Frazer keeps talking about resonance. Is he talking about specific molecular resonance, because I do not think that this exists and if it does exist how do we know when it is going to be specific for humans?

DR. FRAZER: This is nuclear magnetic resonance or electron paramagnetic resonance, which are specific molecular resonances employing both very specific frequencies and an ordering magnetic field. This has nothing to do with the usual discussion of specific resonance frequencies for molecules below approximately 35 gigahertz in the absence of a strong magnetic field. I do not think that such resonances exist in that range, myself, but it is not necessary to invoke resonances in the range below 35 GHz. to produce effects with a high field. George Thurston proved this 10 years ago when he did polarization spectroscopy. Nuclear magnetic resonance has been used since about 1950, since Block and Purcell actually came up with the first successful hydrogen spectrum. It is an identification of chemical species. Alcohol, for instance, has a three, two line spectrum clear to any organic chemistry student. Nuclear magnetic resonance, since its introduction, has become used by organic chemists as a primary means to identify organic compounds. Electron paramagnetic resonance, on the other hand, has been used to follow free radical formations in many processes in tissues and cells and in organic reactions. These are very specific spectroscopic techniques.

DR. ALICE FABIAN (New York State Health Systems Management): Dr. Frazer, has any work been done in activation of viruses, specifically smallpox and polio, in individuals who have received hyperthermia, and what effect does this have on the public health point of view over all?

DR. FRAZER: So far as distinct work in detecting communicable diseases in general, not just the kind of diseases you mentioned, I think it has been totally ignored. In defense of the industry, as it were, I think that the kinds of screens used in experimental protocols would have picked up any widely disseminated disease. They would not have picked up such things as activation of bacteriophage. I think that it is something to examine because an animal is a walking vessel of parasites. One primate becomes a very large number of data points, and gives information on immunologically related coexistence of the host and the parasite. Grinding work, I concede, but it should be taken up. At the moment, there is no such program.

DR. POLLACK: Relative to Dr. Johnson's question, one thing Britton Chance's work showed was that nuclear magnetic resonance analysis can identify molecular species specifically produced by the metabolism of specialized cells. This possibility is being investigated at Yale, using this technique to scan for micrometastases not identified by ordinary diagnostic techniques.

DR. FRAZER: Britton Chance showed ATP, ADP, AMP, creatine phosphate in one scan, which could then be altered by the induction of hypoxia. I am of that generation which would have been jumping around on one leg just for getting the spectrum in a tube, much less in a small part of the cortex of the intact animal. This is a perfectly permissible use of that technique and it should be widely applied. Both Damadian and Bramley and Harris seem to have found specific "tags" for tumor cells that might be exploited.

MR. RON MELNICK (Polytechnic Institute of New York): Is the effect on the phage or on the bacterial cell?

DR. FRAZER: The effect is first on the bacterial cell, then one finds nonreceptive phage incorporation in the first experiment. We melt the bacterial membrane and then introduce the phage. The second effect we demonstrated was on the phage itself, where we had low temperature during radiation and produced noninfectivity.

MR. MELNICK: Are there changes in phage specificity?

DR. FRAZER: We don't know yet. We expect that there are.

MR. MELNICK: Have you eliminated the possibility of latent phage activation?

DR. FRAZER: Not completely. We have in the sense of control survivability of C-600 at the beginning, but I am not absolutely positive.

MR. MELNICK: Do you have to irradiate both the bacteriophage and the *E. coli*?

DR. FRAZER: If one radiates the two together one does not get incorporation. Incorporation and lysis occur only with preradiated *E. coli*.

MR. MELNICK: It seems interesting with the use of microwave tumor therapy. Should any negative aspects be brought out? For example, might internal hemorrhaging develop?

DR. JOHNSON: There are certainly negative effects but not internal hemorrhaging. Temperature measurements of deep structures are difficult. Some vital organs have a very small diffusion rate and can be overheated. Examples are the spinal cord, the eye, and its lens. Any other areas with a very low diffusion rate could be damaged. One requires very well-controlled conditions, and even then hyperthermia is very difficult because of the problem of having really good nonperturbing temperature probes if microwaves are used.

Dr. Frazer, when you discussed the bacteria experiments, were you talking about heat or heat plus the microwaves?

DR. FRAZER: It has been shown that one can cause transitions in the lipid membrane of bacteria with hyperthermia. It depends on the lipid composition of the membrane so that part is simply temperature. The effect on the viral survivability and lower temperature survivability of bacteria was surprising. I thought that we would probably get inactive bacteria on a temperature survivability curve. I am in a quandary myself. We also have conducted these experiments with isolated transfer RNA and we know that single strand RNA is quite sensitive to high amplitude RF fields, I stress that the peak amplitudes were 1 to 3 v./cm. up to 30 v./cm. We controlled the duty cycle so that we did not get marked increases in temperature, but those are very high field gradients. These would be equivalent to something like 30,000 volts per meter in air.

DR. JOHN BERGERON (General Electric): I would like to ask Dr. Frazer or Mr. Hunt to comment on whether or not radiofrequency imaging is possible in the region of dielectric dispersion where there is an appreciable amount of differential in tissue.

DR. FRAZER: I make the following proposition. I think one could do imaging with free access to all of the lovely techniques that Glen Engen has in his department at the National Bureau of Standards, Boulder, Colo., which just happens to include some new double six port analytical schemes for 100 kHz. and up; with free access to that plus the various scanning techniques and computers as used by Paul Wacker and with the addition of short pulse nuclear magnetic resonance, one could envisage very useful developments both in imaging and in therapy.

ESTABLISHING SAFETY STANDARDS*

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PEOPLE are concerned about microwave exposure. We can see this in the press coverage given to the beaming of microwaves at the American Embassy in Moscow, the concern over PAVE PAWS in Cape Cod and California, *The Zapping of America,* and the many articles on radar and microwave ovens, which rarely discuss the issue of microwave radiation and safety.

I should also mention the General Accounting Office reports to Congress in this area. People are confused by talk and discussion of high level effects, thermal effects, low level effects, nonthermal effects. They are confused by the concern over microwatts of exposure at the embassy in Moscow, when levels 1,000 times higher are permitted for whole body exposure without time limit in this country by voluntary standards groups, by the Department of Defense, and by Occupational Safety and Health Administration (OSHA) recommendations for human occupational exposure. Public concern also finds expression in claims for disability brought by individuals who allege injury as a result of occupational microwave exposure. And sometimes these claims are honored.

If scientists are divided on the potential risks that may be associated with microwave exposure, so are the nations and the scientific establishments within them that are responsible for developing and enforcing standards for human exposure.

In a simplistic way, we could assign a number to the difference of concern among nations. Some nations are 10 times more concerned than others about microwave exposure and some nations are 1,000 times more concerned than others about microwave exposure. And this is reflected in the standards for permissible human exposure that they have established.

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A degree of ferment is apparent as we survey what is being done in response to these concerns among lay people, scientists, and nations. The World Health Organization is currently developing a criteria document on microwaves. This document will review existing knowledge in this area and will make some recommendations that may have a bearing on national microwave standards and on microwave safety in the future. The European Office of World Health is developing a manual on nonionizing radiation, with one chapter specifically concerned with microwave radiation. This will also review existing knowledge and potentially influence future standards development.

Within our country, the National Institute of Occupational Safety and Health is developing a criteria document on radiofrequency microwaves. This will, in the format of previous documents, review the scientific literature and make a recommendation for human occupational exposure. This will be transmitted to the Occupational Safety and Health Administration for possible promulgation as an enforceable occupational standard.

The regulatory agencies that are a part of the Interagency Regulatory Liaison Group—the Food and Drug Administration, the Environmental Protection Agency, the Occupational Safety and Health Administration, the Consumer Products Safety Commission—are currently in the process of developing a basis for consistent regulatory action in this area. This will include again a review of the adequacy of existing exposure standards, including those currently recommended by the American National Standards Institute (ANSI), OSHA, and those in use by the Department of Defense. Very likely, the National Academy of Sciences will participate in this review.

Finally, the American National Standards C-95 Committee, which published the 10 $mW/cm.^2$ safety standard for exposure of personnel, has for some time been determining the position it will take this coming year with respect to ratification or modification of this ANSI exposure standard.

It is of interest to note that in 1976 Sweden lowered its occupational microwave standard from 10 $mW/cm.^2$ to 1 $mW/cm.^2$. Canada has reduced its published recommendation for levels of whole body microwave exposure that must not be exceeded. These are for indefinite exposure: 5 $mW/cm.^2$ for occupational groups and 1 $mW/cm.^2$ for the general population.

We do face a dilemma. On one hand we deal with an important technological modality. Microwaves have many important uses in communication, broadcasting, radar and industrial processes, in medicine. They potentially hold great promise in medicine and in consumer applications.

Microwaves may provide one significant element in the effort to harness energy from the sun, using a solar satellite to collect the energy from the sun and beam microwave energy to a collecting station on earth for conversion to electricity.

We most certainly want to enjoy the actual and potential benefits of microwave technology. At the same time we want to avoid the potential risks that may be associated with microwave exposure.

A number of years ago the Bureau of Radiological Health faced the task of developing and promulgating a microwave oven standard. Fortunately, this occurred prior to the explosive increase in use of this home appliance. We reviewed literature available at that time. We examined existing standards for permissible exposure in use in this country and abroad. We were concerned about the significant gaps in the literature on biological effects and the preoccupation in this country with acute, high level studies conducted under the military Tri-Service Program. We came to the documented conclusion that the emission standard for microwave ovens would have to provide significantly greater protection than that provided by the standards published by ANSI.

The 10 $mW/cm.^2$ standard, as well as the far more conservative standards in use at the present time in Russia, Poland, Czechoslovakia and so on, are standards that limit whole body exposure. They are exposure standards. The microwave oven standard, on the other hand, is an emission standard. It sets limits on the maximum leakage allowed from the appliance. The standard promulgated by the Bureau of Radiological Health limited such leakage to 5 $mW/cm.^2$, measured two inches from any accessible surface of the oven for the life of the product.

The characteristics of oven leakage are such that as one moves away from the oven the measured leakage levels fall off very rapidly, approximately as the inverse square of the distance. Thus, at four inches the leakage level would be one fourth of that observed at two inches and so on. At any arm's length the maximum permissible leakage translates to approximately 0.1 $mW/cm.^2$, a level which is permissible under the very conservative Russian standard of two hours per day. Beyond 44 inches the levels fall below those of the Russian standard.

The practical impact of the microwave oven standard is to provide a level of protection that is generally compatible with that provided by the Russian standard. The standard on microwave ovens is conservative and limits practical exposure to levels well below those that might produce biological effects demonstrable through laboratory experimentation. We enforce this standard rigorously.

The general acceptance of the product may in part be due to the certification provided that such products are manufactured under and comply with the applicable HEW safety standard. And let us keep in mind that this standard is applicable for the life of the product.

We believe that safety standards should be developed openly, with the broadest possible interaction between all concerned parties. This includes members of the general public, state and federal health agencies, and affected industries. The basis for decisions should be carefully documented. At the time ANSI promulgated its microwave safety standard, for example, it did not provide documentation of the biological or scientific rationale for its choice of 10 mW as a safe level. We hope that this will be corrected in the future actions of this body.

For a standard to be a safety standard, it must by definition offer protection. Such a standard differs from permissible exposure guidelines or operational limits. The latter may be set arbitrarily. Indeed, an operational limit may be set at a level associated with significant risk to an exposed individual.

A safety standard must recognize that individuals in the population to be protected vary in health status and sensitivity to insult. Levels in the standard should protect these sensitive individuals. This could, for example, include but not necessarily be limited to pregnant women, children, and individuals with circulatory or other health problems.

If significant gaps in information on the biological effects of radiation exposure exist, and they most certainly do exist, these include again things like studies involving chronic repetitive exposure, delayed effects of low level exposure, and so on, then it may become necessary for us to incorporate increased factors of safety into the standard.

This may assure adequate protection while additional experimental and epidemiologic data are developed through research.

We should not compound the already formidable problems of extrapolation from animals to man by extrapolating risk from one frequency to another. The latter will make untested assumptions, including the assumption that all biological effects are thermally based.

Standards and regulations are costly to develop, promulgate, and enforce. We should, therefore, make every effort to determine that the standard or regulation will be of value, that it provides a benefit, and that the benefit justifies the cost. If there is no benefit, including avoidance of risk, there may be no justifiable need for a standard.

A very significant problem associated with microwave standard development has been the limited data available for risk assessment. In this country much of the early research was performed under the Tri-Service Program. It concentrated primarily on high level acute studies, and it was predicated on the thesis that microwave exposure caused tissue heating and tissue heating was responsible for most of the observed effects of microwave exposure.

Scientists in the Soviet Union and other Eastern European countries focused on effects of lower exposure, on the effects of chronic or repetitive exposure. There was little or no contact, however, between Eastern and Western scientists and a consequent lack of confidence in Eastern European work by many scientists in the United States.

In October 1973 the Bureau of Radiological Health organized a symposium on the biological effects and health hazards of microwave radiation. This symposium was held in Warsaw and brought together for the first time 60 investigators from 12 countries, including the leading scientists from the United States, Canada, Sweden, the U.S.S.R., Poland, and Czechoslovakia. The symposium provided the first opportunity for scientists from these countries to engage in scientific dialogue, exchange information, explore differences, identify areas for future research, and develop a basis for future collaboration. Subsequent to this symposium, though not necessarily connected with it, the area of physical factors, including radiofrequency microwaves, was added to the program of U.S.-U.S.S.R. environmental research collaboration. This collaboration, coordinated by our National Institute of Environmental Health Sciences, expanded the contacts between Soviet and American scientists and substantially increased the exchange of information and research data between scientists in both nations.

We hope that the enhanced international contact and exchange has improved mutual understanding, increased mutual confidence and provided the basis that will serve to narrow the differences which currently exist in the various national standards for human exposure to microwave radiation.

But we should not be misled. No amount of well-intended dialogue alone can improve the biological basis, the health basis, for standards. More experimental research and more epidemiologic research conducted by scientists with appropriate expertise is needed. As our data base improves, so will our ability improve to develop standards which will enjoy our confidence and will merit the confidence of the public we serve.

Questions and Answers

MR. KEVIN T. MCCARTHY (Connecticut Department of Environmental Protection): Dr. Shore emphasized that the emission standard applied for the life of the product. Does that mean that the company is responsible for the life of the product?

DR. SHORE: Microwave ovens manufactured after the effective date of the standard must comply with the emission limits in the standard. This is basically what it amounts to. Suppose we were to find a line of ovens that has a problem years after they have been manufactured? This has happened already, you know.

MR. MCCARTHY: Is the company responsible for bringing those ovens up to standard and repairing them?

DR. SHORE: In general, the answer that I would give you to that question is yes.

MR. MCCARTHY: What I was really looking for was just a public response.

DR. NORMAN SIMON: Again, in keeping with the kind of question the physician meets from his patient, may I ask you two questions, Dr. Shore? First of all, as a regulator, how often should a housewife have her microwave tested for leakage? This question is the one most frequently asked of the physician. My second question is, if a person lives in a penthouse two blocks from the Empire State Building, would it be prudent to check the level of nonionizing radiation measured in the penthouse?

DR. SHORE: I take it you are a physician and are asking a biologist. What we both need to do, perhaps, is talk a little bit more closely with an engineer. My understanding is that the design of microwave ovens, particularly those that use choke seals at the present time, is very good in preventing leakage of microwaves. Now that is a biologist's view of the problem. I do think that you need to have an answer from somebody with a different background than mine.

DR. SIMON: Perhaps we ought to call on Mr. Villforth. I ask you the question as a physician. I thought that the Bureau of Radiological Health has helped to promulgate the standards of safety for suppliers. Perhaps you could answer the question as a matter of record.

DR. SHORE: Routine surveys conducted by the Food and Drug Administration inspectors will pick up any situations in which we have problems with a particular line of products. A number of the recalls that we have had in the past were based on information developed through our inspection program so we do inspect ovens, and we do test ovens for lifetime performance in our own laboratories. We have a fairly good idea about the kinds of problems we may encounter and we try to deal with these, where possible, in advance.

DR. JOHN M. OSEPCHUK: If Dr. Shore will not brag about how well he is protecting the public, I shall do it for him. Before the federal government got into the act there were no standards and, without these, people did not know if ovens were safe or not. The government developed a very rigorous standard that specified not only a limit on emission but also provided other protection: concealed interlocks, prevention of object intrusion into holes, a device to monitor interlock system, etc. These measures, together with the very small chance of people getting significant exposure during typical operation of an oven, ensures a high degree of safety. Since the microwave oven is being used by an uncontrolled population, people who are generally not capable of measuring leakage and interpreting it, the standard must be rigorous enough to give peace of mind to the general public without leakage monitoring. And I think the standard does give that.

DR. SHORE: In addition, I might mention that the entire record of enforcement and compliance of the Bureau of Radiological Health and the Food and Drug Administration is a matter of public record and is available to the public by specific request.

DR. SIMON: I wanted to get that on the record. It is very reassuring to us, especially since more microwave ovens were sold this year than conventional ranges in the United States. I am not asking about something that doesn't affect many of us.

My second question, Dr. Shore. Should people who live in a penthouse high up in the City of New York near the Empire State Building have their nonionizing radiation exposure measured?

DR. SHORE: I can't answer that question for you. I think that your question should be directed to someone that has been doing that kind of measurement and he is sitting right in front of you—Mr. David Janes of the Environmental Protection Agency.

MR. JANES: We talked about this a little bit yesterday. I don't know how one evaluates what it takes to give an individual assurance. The question revolves around one of apprehension. The measurements that we have made in tall buildings fall, for the most part, well below anything that we would consider recommending at the present time as an exposure guideline. So, if you were to ask me if I would make those measurements in my own apartment, I would say no. But you have to make some decision about how you define prudence and how you handle apprehension. As I indicated yesterday, levels significantly greater than at ground levels, say factors of 10, will not occur in the upper floors of tall buildings unless very close to the center of radiation of a nearby antenna.

DR. SHORE: I believe that the fact that you asked such a question again points up the kind of public concern that exists and the need to devote great care to the development of protective standards. I think that we must take very great care to determine what is a permissible or a safe exposure. This is not a decision which the public wants us to take very lightly.

MISS HEALER: I would like to comment on microwave ovens. We are holding microwave ovens to a standard of safety far in excess of anything that we apply to conventional ovens, either gas or electric. There isn't a three-year-old in the world who can't walk up and put his hand on a totally exposed element on the top of an electric range, and yet none of us is terribly worried about that. I think that illustrates the point I was trying to make earlier about the difference in our attitudes toward the tangible, the known, and the obvious, as compared to our fear of the unknown or the less obvious or familiar.

DR. LOUIS SLESIN (Natural Resources Defense Council): I would like to address Dr. Simon's question again. I think the number of measurements that have been made in tall buildings in urban areas is very, very small compared to some of the measurements that have been made at ground level. I have gone to considerable trouble to try to find what measurements have been made and I think there are maybe four or five measurements in Chicago, Miami, the Empire State Building, and the World Trade Center. Those measurements were up to about 70 or 80 μW/cm.^{2} Looking at the data that Mr. Janes showed yesterday, the average median value at ground level is in tenths or hundredths or even thousandths of microwatts. So by simple multiplication one can see we are getting up to something like

10,000 times higher the exposure in tall buildings. I would like to encourage the Environmental Protection Agency and anyone else who has the equipment and the money to do those measurements so that we can answer Dr. Simon's question better.

MISS HEALER: I think Mr. Janes indicated that the Environmental Protection Agency is in the process of trying to define those situations. In fact, the situations he selected for measurements—i.e., upper floors of tall buildings—were specifically chosen to put him very close to the broadcast antenna and at the level of the main beam. Such conditions are not commonly found. The current emphasis of the Environmental Protection Agency is to try to locate and characterize radiofrequency environments in similar situations.

THE MICROWAVE SYNDROME*

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A new disease, the microwave syndrome, is recognized. The recent publicity of the radiation of the United States Embassy in Moscow, coupled with the Senate hearings on radiation health and safety, the impact of Canadian proposals to lower their general population nonionizing radiation standard, and the numerous reports on nonionizing radiation appearing in the national media have combined to increase public awareness, interest, and, what is more important, anxieties, about the question of nonionizing radiation.

The setting of standards for maximum exposure limits will not relieve the problem unless, as Morris Shore pointed out, they are supported by public opinion. However, the manner in which public opinion is developed is a very key part of the story.

Standards, of course, have to be based on hard scientific information and not upon emotional appeals developed from the anxieties of those misinformed or incompletely informed about the situation. Any standards based on ill-informed or uninformed public opinion will obviously fall apart like a house built on shifting sands.

I would like to reopen the question of the media approach to this subject. As a matter of fact, Dr. Donald Justesen yesterday made some very pertinent remarks on this very subject and I must agree with what he said. I shall reinforce the statements that he made yesterday.

But even the media themselves recognize these problems. For instance, Robert Clark, who is the executive editor of the *Courier Journal and Times* of Louisville, Ky., quoted Walter Lippman, who more than a half a century ago said "There is everywhere an increasing disillusionment about the press, a growing sense of being baffled and misled." He went on further to say, "The point is that there is deliberate bias, advocacy in the news

*Presented as part of a *Symposium on Health Aspects of Nonionizing Radiation* sponsored by the Subcommittee on Public Health Aspects of Energy of the Committee on Public Health of the New York Academy of Medicine and held at the Academy April 9 and 10, 1979.

columns, selection of assignment of certain stories and others for political and economic reasons, failure to get both sides of the story, wherever possible. These are evidence of bias and unfairness and must be avoided by any self-respecting, ethical member of the press.'' Walter Lippman, 50 years ago, I think, was quite cognizant. Perhaps, he was a little bit strong on this, but from time to time, one must, as the press does, overstress a point to get it across.

I would like to compare some of the newspaper reports on the Moscow situation with the actual facts, as reported and developed by the Johns Hopkins report and by my observations and those of others who were in Moscow over a period of time.

News media reporting leaves much to be desired. In the December 20, 1976 issue of the *New Yorker* magazine, a reporter stated that the *Los Angeles Times* quoted Ambassador Stoessel, United States chief of the mission to Moscow at that time, as saying that the risk of microwave radiation was greater for pregnant women and the other possible microwave hazards, including leukemia, skin cancer, psoriasis, cataracts and emotional illnesses. As one who was at that briefing and who incidentally helped to prepare the briefing for the Ambassador, I deny these statements that appeared in the *Los Angeles Times*. I never wrote them and I never heard them at that point in the hearing or at any point in the hearing.

The insinuations and inuendoes by the writer that the Department of State accepted that the microwave radiation of the upper floors of the chancery was considered hazardous were not true. The story as it appeared in the *New Yorker* made it appear as though the reporter was there. He was not. The Johns Hopkins report, of course, does not support the allegations of this particular reporter.

In the editorial section of the *Washington Post* on Tuesday, July 11, 1978, a column by Daniel Greenberg was entitled, ''A Microwave Delusion.'' This editorial was based in part on a telephone interview with me. The writer goes on to say, ''But if, as many specialists insist, the radiation is low level and apparently harmless, then it is worth considering how few facts and a lot of hysterical ignorance have acquired an unjustified importance in an international relationship.'' This is very good reporting.

In contrast to this approach was the article in *Time* magazine of August 28, 1978. Again I was interviewed by telephone for this story. I gave the identical information to *Time* as I had to the syndicated columnist. The results were quite different. The title of the *Time* story was, ''Are Americans Being Zapped?: The Microwave Controversy Generates Demands for Action.'' The story relates a series of alleged individual experiences and pending lawsuits. *Time* stated, ''Investigators claim to have found an unusually high incidence of cancer and blood disorders amongst embassy personnel, as well as a number of birth defects in their offspring.'' They do not name the investigators, nor do they give any specific data. The subsequently published Johns Hopkins report absolutely refutes every single one of those implications in the magazine story.

Contrast these statements with the painstaking, in-depth study carried out by the Johns Hopkins University School of Public Health and Hygiene for the Department of State. The Hopkins investigators concluded that there is ''no convincing evidence discovered that would implicate the exposure to microwave radiation by the personnel in the Moscow embassy in the correlation of any adverse health effects as of the time of that analysis.''

Parenthetically, it can be pointed out that more than one third of the study group and more than 52% of the person years involved had had from 10 to 23 years postexposure experience. The numbers are small, but they do not indicate any trend toward late-developing complications.

The *New Yorker* and other reporters have called attention to the fact that two former ambassadors to Moscow have died of malignancies. By implication they blame the microwave radiation. A quick review of the situation in the Moscow embassy points up that less than one third of the total population had ever had any possible exposure to microwave radiation, least of all the ambassadors in question.

In my Senate testimony of June 1977 I stated that prior to June 1975 it was only the west facade above the sixth floor of the chancery that had been exposed to the microwave beam. I made a point of this in my previous discussion on this subject. These two ambassadors each served prior to June of 1975. Their offices were in the southeast corners of the building, far removed from the west facade where the only exposure existed; and they lived in the Spasso House miles away from the chancery. The Spasso House was swept electronically more than once a day, and the only microwaves found were those of the microwave oven in the ambassador's private quarters on the second floor. So that these men had not been exposed to any microwave radiations in Moscow, and the implications and inferences that their deaths were due to this exposure is obviously all wrong.

The Johns Hopkins report specifically states that there were no extraordinary incidences of cancer, brain disorders, or loss of vision in any embassy personnel. While the focus of the Hopkins study was the microwave problem, it did point up that the morbidity and the mortality of the male employees in the Moscow embassy was actually half that of the standard rates in the continental U.S. This, of course, was a tribute to the screening procedures of the Medical Services Office of the Department of State.

Let me go on to quote a few things from the book by Mr. Brodeur, *The Zapping of America*. ''Anxiety about the genetic effect of microwaves first came out into the open in December 1971 when the Electromagnetic Radiation Management Advisory Council, a nine-member group that included Dr. Pollack, warned that the consequences of undervaluing or misjudging the biological effects of long-term, low level exposure could become a critical problem for the public health, especially if genetic effects were involved.''

Yes, we made that statement. After Mr. Brodeur pointed out that I was a member of the early group who warned the public about the possible consequences of underevaluating the biological effects of the long-term level of radiation, the author proceeds to accuse me of being part of a coverup. I am not sure what I was covering up when I helped make statements of that sort, but, nevertheless, he said that. ''It (ERMAC) knew of the 1964 findings of Dr. Lilienfeld and his colleagues at the Johns Hopkins concerning the apparent association between radar exposure and Down's syndrome.''

You heard Dr. Charlotte Silverman this morning discuss that. She also pointed out the failure to support these statements in the further evaluation of the data. The author of *The Zapping of America* knew of this, and yet failed to report the second part of the story but only reported the first part. He goes on to say that the types of chromosome aberrations observed in this study are the same as those induced by ionizing radiation in other organisms, including humans. Obviously, no such data were available.

I shall not proceed any more, except to say that the press has the same problem we do with our own medical profession. We have an ethics problem. We have to clean house, and I think the press is going to have to do the same thing with its own. There are good and bad in both professions, and it is of course the millennium if we expect everybody to be perfect.

PUBLIC EDUCATION AND INTEREST IN ENVIRONMENTAL FACTORS*

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AFTER Dr. Pollack's affectionate remarks about the press, I hardly know where to begin.

If we want to look at the reporting of the Moscow episode, one very important element to keep in mind is that for the first few years, although the State Department was aware that the embassy was receiving these microwave beams, it concealed this fact. It not only concealed the fact from the general public, but actually concealed it from the employees of the embassy, sowing an immense amount of distrust and creating among the families there a good deal of hysteria. I think that has been the seedbed from which a lot of the press reporting has sprouted.

Whether to trust our government has been a question very much in the public mind during recent years, but the reports that come out of Washington and many other places about what government is doing are often received with a good deal of skepticism. But I ask, in view of what has happened in recent years, whether that skepticism is justified. The incident at Three Mile Island, for example, is something that we were virtually promised time and time again could not happen. In the very midst of this episode, there was blatant, outright lying about what was going on there. Fortunately, the Nuclear Regulatory Commission got its act together and decided that, as a last resort, telling the truth might be a useful thing to do. It is quite interesting that when Dixie Lee Ray was chairman of the old Atomic Energy Commission in 1975, one of her proudest boasts was that from then on the Atomic Energy Commission would not lie to the public—and she said so publicly.

Dr. Pollack quoted Walter Lippman's remark about feeling very disil-

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lusioned about the press 50 years ago. People are always disillusioned about the press. Show me that golden age in which people say we at last have a press that is meeting the needs of our people. The reason we do not have a unanimously revered press is that there is no such thing as "the press," any more than there is the medical profession, the academic community, or the scientific community. The press ranges from the *National Enquirer* to the *New England Journal of Medicine*. It encompasses *The New York Times* and country weeklies. That is the press. Those publications appeal to very different audiences, and they work in very different time frames.

There is no question in my mind that the Johns Hopkins study was very reliable and probably told us the last word on the Moscow incident. It was two or three years in the works. Most of the newspaper and magazine reports Dr. Pollack mentioned were probably prepared in a day or two.

One might say that haste is the great enemy of the press, and that this is a problem that is really of the press's own making. No question about that. The press is always in a big hurry to get the story out because it has a product that it sells every day or every week. There are competitive pressures. I do not offer this as an excuse; I offer it as a description of what the press is. The press is, first of all, a business. It has to stay alive. It has to sell. It sells because it carries information on a timely basis. It is not going to have a report three years later about what was happening at the Moscow embassy. Whatever it has this afternoon is going to be in tomorrow morning's paper. This, then, puts a heavy burden upon people who want to see reliable information get into the press.

Dr. Pollack referred to the inconveniences and the frailties of the telephone interview. I think most reporters would far prefer to have a face-to-face interview. It is very hard to get people in the State Department to sit down with you when you want them; it is much easier to get them on the telephone. A good deal of journalistic business is conducted over the telephone for obvious reasons. A lot of business is conducted over the telephone.

I was invited to this symposium to speak on "Public Education and Interest in Environmental Matters." I would say that there is not much education, but there is a great deal of interest, much of which stems from the fact that we are now in a scientific and technological era in which very minor, invisible insults can have long latency periods and can then result in dreadful consequences. The public has only fragmentary information about how these processes work. Nevertheless, it knows something is going on out there and accompanying this awareness is a general feeling of distrust that the public acquired through very hard experience. We can look at some of the great milestones of this process: Watergate, the nuclear business, and so on.

I think it is very easy to make the press a whipping boy. I would like to see it whipped for its real failings—not because it has to work quickly, not because it is sometimes wrong, but because it is often too much concerned with official pronouncements, with getting the news the easy way, with getting it over the telephone, getting a handout. It is too easily manipulated by organizations that have the wherewithal and the resources to manipulate it. Everybody shows up for a press conference if the proper authority calls it. Very few reporters have the time or the energy, nor do their papers have the resources, to go out and really look for news.

I sense a certain kind of smugness on the part of some of the other speakers that I think boils down to a feeling that microwaves are okay, and why does that dumb public out there feel so suspicious of them? Where has our profession failed? Why don't they realize that this stuff is good for them?

I think the reason the public does not think this stuff is good for them and that so much suspicion is encountered is that, first, there is no unanimity in the scientific community and, second, a large part of the conversations here have been concerned simply with gaps in our knowledge. We do not know this, we do not know that. We do not know an awful lot. There is vast ignorance that we are concerned with. Nevertheless, these products are on the market. The exposure is taking place, just as the nuclear plants are being built and more, apparently, are going to be built. And the public is being told that even though there are large gaps in our knowledge, please be assured everything is really okay. It seems to me that this is a formula for disastrous public relations and, if the scientific community does encounter such relations, I think it should understand where they are coming from.

Questions and Answers

DR. JOHN OSEPCHUK (Raytheon Company): Mr. Greenberg, I think you heard some of the horror stories that Miss Healer and other people referred to. One of the things the press could try to learn is the language, so that at least they know that x rays are not microwaves and they do not communicate to the public that they are the same.

MR. GREENBERG: How often does that error occur?

DR. OSEPCHUK: Too often. Miss Healer read from *Time Magazine*. A front page Associated Press article states that if one wants to reduce one's exposure after the Three Mile Island incident, one can talk to one's physician about trying to cut down medical x rays, stay out of the sun between 10:00 and 2:00, and keep away from microwave ovens. Front page, Associated Press. She read it in *Time*. Can't we expect the press at least to take a one- or two-day course in what radiation means and what microwave means?

MR. GREENBERG: I cannot defend those mistakes. My impression is that, as deplorable as they are, fortunately they occur rather infrequently.

DR. OSEPCHUK: As a member of a company that manufactures microwave ovens and has to answer letters, believe me, too frequently. I was at a party following the *Consumers' Union* report in 1973 and a young, brilliant M.D. came up to me and said, "Oh, for heaven's sakes, I hear that you were involved in that Senate testimony. I did not know that microwave ovens emitted radiation. Is it gamma rays or beta rays?" Now, he is a brilliant, young M.D., and if he is so confused by the media, what about the poor general public? This has been going on for years. I shall just say that there is a problem.

MISS HEALER: I want to extend my sympathy, Mr. Greenberg, because if confusion and misinformation can exist within the medical and scientific community, as Dr. Osepchuck just illustrated, then this certainly applies to the press as well.

DR. MERRIL EISENBUD (New York University): I, like many others, have been greatly concerned about this problem, although I have never been concerned about anything I ever read by Daniel Greenberg or Walter Sullivan or, for that matter, any of the science writers that I can think of. I may be wrong on that.

The problem is that the press has access to high quality science writing, but assigns the relatively complicated subjects to general reporters. I vowed that when I came here that I was not going to talk about Three Mile Island, an incident about which we do not yet have all the facts, but I think there are already lessons to be learned as far as communication with the public is concerned. The accident occurred only 10 days ago but congressmen have already been visiting, and I understand that the press is mobilized in greater numbers than at any time since the Kennedy assassination. There has been enormous pressure for information, which I suppose has been released prematurely in many cases. My sympathies go to the engineers and others operating the Three Mile Island plant who probably did not understand the whole story during the first day or two and gave out what seemed to be misinformation because of the pressure they were under.

I shall illustrate three points that I think seriously misled the American public. One was a United Press International photograph of the plant in which the caption read, "Infrared photograph of Three Mile Island showing the glowing radiation." The public was deliberately misled into thinking that the infrared radiation in the photograph was ionizing radiation.

The second was the permissiveness of the press in granting a press conference to Ernest Sternglass, who had been thoroughly repudiated by the Pennsylvania State Health Department for other sensational statements which he had made in the past. You will recall that he flew over the plant in a helicopter at a time when he had no business being anywhere near the site—he could do no good—and said that he detected radiation some hundreds of times above normal, which means nothing.

Finally, although it was well established early in the game that radiation levels to which people were exposed offsite were on the order of a few microrads, that it was due to the presence of noble gases and that only about 20 picocuries of iodine per liter showed up in milk, which is really low level. This was not emphasized by the press although the information was available.

The press is so influential now, so well-organized, and the newspapers are so closely coupled with the electronic media, which operate so fast and with such enormous organization, that I believe there ought to be a board of critics. Such a board should consist of people like Daniel Greenberg and Walter Sullivan and other science reporters who would take complaints from responsible members of the public. There is a need for an internal censorship of the type that we all enjoyed back in the days when the film industry had it. At one time they were doing a good job of censoring themselves and everybody had freedom.

MR. GREENBERG: First, in response to one of the points that you made, the reporters at Three Mile Island were not climbing all over the engineers and technicians in those first days while they were trying to get the reactor back under control. They were not allowed anywhere near the reactor building. Initially, there was a spokesman from the company—the one who, let us say, was somewhat off the mark with his reports as to what was going on. Then he was supplanted by Denton from the Nuclear Regulatory Commission. It is a very simple standard process in a complex and fast-moving situation that one appoints a spokesman who provides reporters with the information that is conveyed to the outside world.

I think it was very important in those early hours to get information out to the public because the initial report was that something had gone dreadfully wrong with the reactor and that it might be the ultimate disaster with a nuclear reactor. I do not think if one had a news blackout, let us say for four or five hours or perhaps even for a day, that this would contribute to public understanding. So there was a necessity to get information out even though it turned out to be fragmentary, but reasonably reliable, information.

It is very interesting that, in a poll considering the public attitudes toward the press, the public manifested great confidence in the press but not in the nuclear or the government spokesmen.

Dr. Eisenbud asked why the press should not censor itself. One gets into very sticky territory there. Why did doctors resist PSRO? One does not like anybody looking over one's shoulder. The Constitution says, "Congress shall make no law...." The press does have certain quality control mechanisms. A reporter who makes too many mistakes is not going to hold on to his job very long.

What I frequently find when people complain about the press is that when one asks them to cite chapter and verse, often it does not stand up. For example, Dr. Herbert Pollack said that in his *New Yorker* articles Brodeur was trying to convey the impression that he was in Moscow when in fact he was not there. I do not think that he was trying to convey the impression that he was in Moscow. The vantage point from which he was writing was perfectly clear to any reader and I think anyone who infers that there was a bit of sleight-of-hand on his part is reading something between the lines that does not exist.

DR. SIMON: As chairman of this meeting I want to thank you very much for coming here. I speak not to praise you nor to bury you but to join you. Indeed, we physicians have the same problem that you seem to have, and we have invited this illustrious group to help us to evaluate the presumed or the real hazards of microwave radiation.

You in the press, have a responsibility, and I guess our relation to the patient who faces us is about the same as your relation to the one who picks up your column and reads it in the morning. However, I think that our approach, since it is not as ephemeral and since we cannot throw away the column after we have read it, needs a great deal of careful reading of the proceedings, and I am grateful to you for your comments as a part of the proceedings of the meeting.

MISS HEALER: I add my thanks to Dr. Simon's and also comment that I tried at the outset to define a context for this session, much along the lines of Dr. Simon's remarks, I would like to respond to the comment that the expert community is smug. I sincerely hope this has not been the impression. You mentioned a lot of references to "we don't know's." I think that indicates humility. Areas of uncertainty are elaborated in an effort to be straightforward, factual, as fully informative as possible, and not misleading.

The scientific community is rigorous in caveating, qualifying, and quantifying its statements. For example, it has been said that a scientist never says "never," and we speak in funny units—megahertz and milliwatts, etc. That is why in my opening remarks I said that I am not certain we are effective in communicating directly to the public and that we need the informed assistance of the press and of the medical community, which deals with the public on a more personal, one-on-one, basis.

When I speak with people who express concern about dangers in circumstances where there may be no exposure or fields of only fractions of a microwatt per square centimeter, I frequently step back and remind myself that the only reason I don't share that particular concern is because of what I know due to the nature of my work. We are all members of society. We have families, children, and the same kinds of concerns. Matters involving health and safety affect us all. The expert community is distinguished in only one way, i.e., we happen to be involved in this particular area and are, therefore, more aware of what is known and what is not, but there is no reason to be cavalier about that.

A LOCAL HEALTH AGENCY APPROACH TO A PERMISSIBLE ENVIRONMENTAL LEVEL FOR MICROWAVE AND RADIOFREQUENCY RADIATION*

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FOLLOWING discovery of x rays and radioactivity, medical and experimental scrutiny over a long period of time identified the potential for harmful biological effects in living systems of ionizing radiation. Research in this direction was enormously intensified with the advent of nuclear weapons and nuclear power generation.

On the other hand, nonionizing radiation in the radiofrequency and microwave regions of the electromagnetic spectrum has received comparatively little investigation and environmental regulatory attention. With increasing utilization of the radiofrequency spectrum in recent decades, including radio and television broadcasting, radar for commercial transportation control and military observation, such consumer products as microwave ovens, diathermy equipment employed in medical therapy, and other applications, warranted concern and interest in public health control of possible harmful biological effects of nonionizing radiation in humans have surged.

The limited biomedical observations with human experience and fairly extensive animal experiments strongly indicate a potential for biological damage in living systems, with varying degrees of probability, depending upon such physical factors as levels of pulsed or continuous radiofrequency or microwave power and wavelength of transmission.

Among representative effects demonstrated in diverse biota, or reported in medical observations of humans, are cataract production, central nervous system impairment, chromosomal and genetic anomalies, blood-

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system changes, and adverse influences of irradiation on prenatal body and brain weight.

In June 1978, as director of the Bureau for Radiation Control of the New York City Health Department, I recommended to the Board of Health of the City adoption of a regulation to the Health Code to set maximum permissible levels for potential exposure to microwave and radiofrequency radiation to members of the general public in uncontrolled or unregulated areas. The Board of Health approved this regulation for publication and solicitation of public review and comment. As of this date (April 1, 1979), the regulation is still under consideration by the Board of Health but has not been adopted. This paper comprises essentially my personal scientific justification for the proposed regulation and does not represent the official point of view of the New York City Department of Health or Board of Health.

Need for an Environmental Standard

Though federal occupational guidelines have been promulgated for civilians and military personnel potentially exposed to microwave/radiofrequency radiation in connection with working activities, analogous environmental standards for individuals in the public sphere have not been enacted by legislative or regulatory agency action. Even the current federal Occupational Safety and Health Administration (OSHA) permissible working level may be considered advisory rather than mandatory and, according to at least one judicial opinion, not statutorily enforceable.

Failure to evolve environmental standards, for whatever reasons, is deplorable from several points of view. Widely publicized media discussions of alleged deleterious physiological effects of microwaves has created public apprehension and concern without acceptable biomedical affirmation or refutation. The absence of standards leaves the potential for unwarranted assertions of hazard and peril which may conflict with sound policy in public health and safety.

The thrust of the proposed regulation is based upon the thesis that officials, biomedical practitioners, and citizens are entitled to legally enforceable standards which realistically address physical environmental factors with potential health implications.

The recommended regulation was derived from these main considerations:

1) Biological and clinical effects have been exhibited on a sufficiently

broad scale by laboratory experiments and clinical observation to demonstrate the potential for physiological impairment in humans from microwave and radiofrequency radiation from various power or energy-density levels. Physiological effects demonstrated in animal experiments include cataractogenesis, hormonal alterations, chromosomal anomalies, and hematological changes. Less certain but probable effects include central nervous system impairment and mutagenesis. In the realm of conjectural but possible effects, warranting the most careful public health scrutiny, are mutagenic, oncogenic, and teratogenic influences.

2) The very approximate threshold for some observable effects of varying public health implications appears to be between 1 and 10 $mW/cm.^2$ for noncontinuous exposures. Of course, not every microwave or radiofrequency induced physiological perturbation need be a clinically significant hazard or impairment. Evaluating available research evidence, an occupational permissible level of 0.5 $mW/cm.^2$ would be indicated. This is a factor of 20 less than the current OSHA guidelines for working areas of 10 $mW/cm.^2$

3) Environmental standards should be established at some lower level as distinct from occupational permissible levels. A working population exposed to a potentially hazardous etiological factor is in general subject to biomedical surveillance and awareness, and to industrial hygiene or health physics administrative control. Environmental standards apply to those without the presumed protection and scrutiny of a regulated working environment. In particular, infants, children, pregnant women, and other particularly susceptible or vulnerable individuals must be protected adequately by applicable environmental standards.

4) Employing an additional safety factor of 10 for a public environmental standard, in contrast to an indicated occupational permissible level of 0.5 mW (500 $\mu W/cm.^2$, one arrives at 50 $\mu W/cm.^2$ in unregulated or uncontrolled areas available to men, women, and children by virtue of residence, recreation, or general public access.

5) The proposed New York City Health Code regulation applies to microwaves and radiofrequency stationary transmitters. However, the biological considerations discussed also apply to the emissions of mobile units, the hazards of which are incompletely evaluated and deserve meticulous public health surveillance. For example, the most commonly employed source of radiofrequency radiation are citizen band (CB) radios operating at 27 MHz. Power densities corresponding to 11.5 $mW/cm.^2$

TABLE I. MICROWAVE AND RADIOFREQUENCY RANGES IN THE ELECTROMAGNETIC SPECTRUM

Microwaves	*Frequency* *300 GHz.-300 MHz.*	*Wavelength* *1 mm.*	*- 1 m.*
Extremely (EHF) high frequency	300-30 GHz.	1 mm.	-10 mm.
Super high frequency (SHF)	30-3 GHz.	10 mm.	- 100 mm.
Ultra high (UHF) frequency	3 GHz.-300 mHz.	100 mm.	- 1 m.
Radar	56 GHz.-220 mHz.	5.4 mm.	- 1.3 m.
Radiofrequency	*300 mHz.-300 kHz.*	*1 m.*	*-1 km.*
Very high frequency (VHF)	300 mHz.-30 mHz.	1 m.	-10 m.
High frequency (HF)	30 mHz.-3 mHz.	10 m.	- 100 m.
Medium frequency (MF)	3 mHz.-300 kHz.	100 m.	- 1 km.
Low frequency (LF)	300 kHz.-30 kHz.	1 km.	- 10 km.

1 GHz. = 10^9 Hz.; 1 mHz. = 10^6 Hz.; 1 KHz. = 10^3 Hz.

have been measured from a hand-held unit which at its full legal output power of 4 watts would have yielded a power of 18.2 mW/cm.^{2} Another area of concern in the citizen band radio is the extensive use of linear amplifiers to achieve high output powers, though illegal by Federal Communications Commission (FCC) regulations.

Legally licensed mobile units employed by police, fire, and emergency response departments also have a potential for exposing individuals in the public environment to hundreds of milliwatts/cm.^{2} in the microwave and ultra high frequency range. Presumably, these transmissions are intermittent and nonsustaining as far as individual radiation exposures are concerned. Their aggregate public health impact deserves careful future scrutiny, but they are not the subject of the current proposed regulation.

FREQUENCY RANGES

Because designations are not uniform in the investigative scientific literature, Table I summarizes the frequencies and wavelengths of the relevant microwave/radiofrequency portions of the electromagnetic spectra discussed in this paper.

SUMMARY OF BIOLOGICAL EFFECTS AND CLINICAL OBSERVATIONS FOR MICROWAVE AND RADIOFREQUENCY RADIATION

It should be emphasized at the outset that the frequency region of interest, i.e., 30 kHz. to 300 GHz., is in the nonionizing portion of the electromagnetic spectrum. Unlike x or gamma radiation typical of the ionizing region of the electromagnetic spectrum, microwave/radiofrequency radiations have relatively low energy in the quantum sense and are incapable of separating bound electrons from atoms and molecules. Though the precise biophysical dynamics of nonionizing radiation are still incompletely understood, the biological modes of action may be characterized in three very general ways:

1) Macroscopic heating or hyperthermia of a whole living organism or substantial part thereof results in sustained elevation of temperature and produces reversible, irreversible, or partly reversible biological changes.

2) Microscopic heating of individual cells or very small sections of an organ produces biological changes of various persistence without perceptible temperature rise in the macroscopic sense.

3) Nonthermal or only partly thermal effects relate to the interaction of impinging electromagnetic radiation with the electric or magnetic fields of living tissues or cells. Not all investigators accept the validity of athermal biological effects, and some argue that such effects are attributable to the microscopic heating mentioned above.

Very approximately, macroscopic heating or hyperthermia would be associated with power densities in excess of 10 $mW/cm.^2$ Microscopic heating would be associated with power densities roughly in the range of 1 to 10 $mW/cm.^2$ The athermal mode would be related to biological effects produced below $mW/cm.^2$ or in the $\mu W/cm.^2$ power-density range.

Table II lists the principal representative biological effects purported to have been observed in various biota from microwave or radiofrequency exposure. Associated with the effect are the frequency and estimated power-density ranges as well as my opinion as to the probability that the effect has been conclusively observed or demonstrated.

Table III lists representative effects claimed by clinical or epidemiological observation of human beings. Most such reports address workers occupationally connected with microwaves or radiofrequency radiation, and information on the frequency range or power density are either unavailable or incomplete. The listings in Tables II and III are suggestive or representative and in no sense even partly complete.

TABLE II. BIOLOGICAL EFFECTS OBSERVED IN NONHUMAN BIOTA FROM EXPOSURE TO MICROWAVES OR RADIOFREQUENCY RADIATION

Biological effect	*Biota*	*Probability of having been observed or experimentally demonstrated*	*Frequency or wavelength range*	*Power density energy density ranges and/or time*	*Comment*
Mortality[5]	Rats, rabbits, dogs	Highly probable	2,800 mHz. (pulsed) mm, 3 cm, 10 cm, decimeter	165 mW/cm.^{2} 40 mW/cm.^{2}-100 mW/cm.^{2} minutes to hours	Apparent greater sensitivity of smaller animals.
Chromosomal[6] anomalies	Chinese hamster, Drosophila melanogaster	Probable	5-40 mHz. (pulsed)	N.R. (not reported)	Also breaks in human lymphocytes in culture.
Central nervous[7] system (CNS) influence		Probable	200-300 mHz.	N.R.	Auditory nerve response not necessarily hazardous.
Oncogenesis[8]		Speculative	N.R.	N.R.	No direct clinical evidence; epidemiological suggestion of carcinogenesis in North Karelia region of Finland.
Biochemical imbalances[9]		Probable	N.R.	N.R.	Citations of many studies.
Cataractogenesis[10] and other ocular effects	Rabbits (New Zealand albino)	Highly probable	300 mHz.	50-500 mW/cm.^{2} 15 min./day, 30 days	200 mW/cm.^{2} no effects 300 mW/cm.^{2} intraocular opacity.
	Rabbits	Probable	2,450 mHz.	250 mW/cm.^{2}	Study suggests less than 10 mW/cm.^{2} not cataractogenic.
Hematopoietic system changes[11]	Rabbits	Highly probable	2,950 mHz. (pulsed)	3 mW/cm.^{2} (cw) 2 hr./day 37-79 days	Difference in iron metabolism between pulsed and cw.
Bone marrow impairment[12]	Rabbits	Highly probable	2,450 mHz.	1.3 W/cm.^{2} 30 min./day 5 times/day 7 days	Leukocytosis, aplastic anemia.

TABLE II. Continued

Biological effect	*Biota*	*Probability of having been observed or experimentally demonstrated*	*Frequency or wavelength range*	*Power density energy density ranges and/or time*	*Comment*
Central nervous system influence[13]	Chicks	Highly probable	147 mHz.	1-2 $mW/cm.^2$	Increase in calcium ion release
Central nervous system influence[14]	Cats	Highly probable	2,450 mHz. (cw)	1.6 $W/cm.^3$ (absorbed)	Functional alterations of brain and spinal cord
Central nervous system influence[14]	Hamsters	Highly probable	2,450 mHz.	25-250 $mW/cm.^2$ 30 min.-22 days	Hypothalamus and subthalamus consistently affected.
Subjective psychological complaints[17]		Possible	N.R.	0.01-10 $mW/cm.^2$ (very approx.)	Wide variety of purported clinical effects
Hematological changes[18] mortality[19]		Probable	N.R.	N.R.	Many blood changes cited; main instability in leukocyte indices. Results essentially not significant in terms of overall causes of death from disease of all kinds.

*General effects[16]
Synopsis of animal investigations in U.S.S.R.; rats, rabbits, cats, mice, birds. Large variety of effects between 1 $mW/cm.^2$ and 10 $mW/cm.^2$ (frequency unspecified) including central nervous system damage, audiovascular system effects. Biochemical changes (e.g., lowered cholinesterase activity, catalase activity, acytylcholine in the brain, increased blood histamine, increased amino acids in the urine). Reproductive function disturbance (e.g., disturbances of the estrus cycle, reduced litter size, increased abnormalities in offspring and anomalies in fetal development.

TABLE III. CLINICAL OR BIOLOGICAL EFFECTS OBSERVED IN HUMANS FROM EXPOSURE TO MICROWAVES OR RADIOFREQUENCY RADIATION

Biological effect	*Biota*	*Probability of having been observed or experimentally demonstrated*	*Frequency or wavelength range*	*Power density energy density ranges and/or time*	*Comment*
Mutagenesis[20]	Swiss male mice	Highly probable	1.7 GHz.	50 mW/cm.^{2}	DNA changes; high mutagenicity index in sperm
Mutagenesis[21]	*Escherichia coli* B, Aerobacter aerogenes	Probable	50-90 GHz.	10-50 mW/cm.^{2}	Basic changes in cell structure and chemistry
Cataractogenesis and other ocular effects[22]		Probable	Not reported (N.R.)	Not reported (N.R.)	Epidemiological studies among microwave workers show increase in lens opacities and retinal lesions.
Teratogenesis[23]	Mealworms larvae of *Tenebrio molitor* (darkling beetle)	Highly probable	9-10 GHz.	N.R. (20-80 mW) total for 20-120 minutes	Teratogenesis precedes presumed thermal lethality.
Teratogenesis[24]	Mice	Highly probable	2,450 mHz.	3-8 calories/gm.	Hemorrhage, exenecphaly

TABLE III. Continued

Biological effect	Biota	Probability of having been observed or experimentally demonstrated	Frequency or wavelength range	Power density energy density ranges and/or time	Comment
Behavioral impairment[25]	Sprague Dawley rats	Probable	1.3-1.5 GHz. (pulsed)	0.65 mW/cm.^{2} (av.) 1.3 mW/cm.^{2} (peak) 0.4-2.8 mW/cm.^{2}	"Docility" induced as well as adverse motor coordination and balance.
Neuroendocrine and hormonal alterations[26]	Rats and dogs	Highly probable	2,450 mHz. (cw)	20-60 mW/cm.^{2} 30-60 minutes	Transient changes ascribed to temperature increase.
Prenatal impairment[27] of body and brain weight	Sprague-Dawley rats	Probable	2,450 mHz.	10 mW/cm.^{2} 5 hours/daily 17 gestation days	Prior work by Rugh et al. at 123 mW/cm.^{2} for 2-5 minutes on 8th day of gestation much worse.
Blood-brain[28] barrier alterations	Chinese hamsters	Probable	2,450 mHz.	10 mW/cm.^{2} 2 hour, 8 hour for one day 8 hour day/for 5 days	Severe brain-barrier effects observed in prior work at 20-100 mW/cm.^{2}

Current Nonionizing Radiation Standards

Table IV tabulates occupational standards for the United States and the generally lower standards of certain Eastern European nations. Standards are given in milliwatts per square centimeter. It is seen that at frequencies above 300 MHz. (1 MHz. = 10^6 Hz.) permissible Soviet power levels are a factor of 1,000 less than the American occupational standards.

One can predict with reasonable confidence that American occupational standards will be revised downward in the future based upon evidence such as that presented in the prior section, but little empirical evidence obtained in American laboratories warrants adoption of the extremely conservative Eastern European standards.

One summary states:

> With regard to occupational standards, there also appears to be developing a trend toward East-West convergence. If the trends in Western research reported above continue, it is not difficult to speculate that the United States' endorsed occupational exposure level of 10 m/cm.^{2} per day might be lowered to 5 mW/cm.^{2} However, additional occupational surveys are needed before such a significant judgement can be made, extrapolation of experimental data to man remains very risky. At the same time, we note that the extremely conservative Soviet standard (0.01 mW/cm^2) is not a particularly defensible one, and that there is a trend in some East European countries to relax this standard by as much as an order of magnitude. If such a trend continues to develop as anticipated, the large disparity between occupational standards in the East and West will be substantially narrowed.[1]

The observers, writing in 1975, anticipate a reduction by a factor of two in the United States, occupational permissible standards. Possibly, the reduction may be materially greater, perhaps by the order of 10. As tabulated above, the threshold for some observable biological effects appears to be between 1 and 10 mW/cm.^{2} For noncontinuous exposures, an occupational permissible level of the order of 0.5 mW/cm.^{2} would be indicated. This is a factor of 20 less than current United States guidelines for working areas.

Measured Background Environmental Levels for Radiofrequency Radiation[2,3]

In one survey performed by the United States Environmental Protection Agency (EPA) covering the radiofrequency ambient environmental bands between 46 MHz. and 900 MHz., power densities encountered fell between 0.001 and 1 μW/cm.^{2} with a median value between 0.02-0.03

TABLE IV. OCCUPATIONAL RADIOFREQUENCY STANDARDS

Frequency	*Exposure time hours*	*U.S.A.* (*milliwatts per cm.*^{2}) *OSHA/ANSI* and/or *U.S. Army*	*U.S.S.R.*	*Czechoslovakia* *CW*	*Czechoslovakia* *Pulsed*
Above 300 MHz. (UHF, SHF, EHF)	24	None	0.001 (proposed)	0.0025	0.001
	8-10	10	0.010	0.025	0.010
	2	10	0.10	0.10	0.040
	0.33	10	1.0	0.60	0.24
	0.10	10	1.0	2.0	0.80
	2 min.	30	1.0	6.0	2.4
30-300 MHz. (VHF)	24	None	0.001	0.0003	
	8-10	10	0.007	0.03	
	2	10	—	0.4	
	0.33	10	—	15	
	0.10	10	—	170	
	2 min.	30	—	1,500	
10-30 MHz. (HF)	24	None	0.004	0.007	
	8-10	10	0.1	0.7	
	2	10	—	11	
	0.33	10	—	382	
	0.10	10	—	4,244	
	2 min.	30	—	38,200	
0.1-10 MHz. (no OSHA standards; U.S.A. listings are those of Army) (LF, MF, HF)	24	51.4	0.03	0.007	
	8-10	51.4	0.7	0.7	
	2	51.4	—	10.6	
	0.33	51.4	—	382	
	0.10	51.4	—	4,244	
	2 min.	51.4	—	38,200	

μW/cm.^{2} Forty locations were surveyed in the metropolitan New York area. The range of ambient values encountered in this region from a minimum 0.000068 μW/cm.^{2} (Tottenville, Staten Island) to a maximum of 4.6 μW/cm.^{2} (Mount Pleasant Street, West Orange, N.J.). The average for these 40 observed locations was 0.22 μW/cm.^{2} including the two maximum values. If the two maximum values (i.e., 4.6 μW/cm.^{2} and 1.9 μW/cm.^{2}) are omitted, the average for the remaining 38 sites is 0.069 μW/cm.^{2} All these measurements were done at street level. Total field-strength measurements reported by the EPA yielded maximum levels for New York City as follows:

	Total field strength ($\mu W/cm.^2$)
World Trade Center	
Outdoor observation deck	6.8
Indoor observation deck	1.2
Empire State building	32.50
Pan Am building	10.3

Two locations, one in Miami (2 Biscayne Boulevard) and one in Chicago (Sears Tower) yielded higher field strengths, 96.85 μW/cm.^{2} and 65.73 μW/cm.^{2} respectively.

PROPOSED U.S. COAST GUARD MICROWAVE TOWER, TODT HILL, STATEN ISLAND

The compelling urgency for promulgation of sound microwave environmental standards is typified by a recent series of events involving senior level municipal agencies of New York City and the United States Coast Guard, an agency now under the jurisdiction of the U.S. Department of Transportation. As part of the New York Vessel Traffic Service System for the Port of New York, the Coast Guard, through a contractor (Motorola Communications and Electronics), is endeavoring to erect a microwave tower facility in the residential Todt Hill area of Staten Island. The facility would employ radiofrequencies in the VHF region (about 10 W at 157 MHz.) and in the UHF microwave region (about 80 W between 406 MHz. and 2,225 MHz.). The proposed transmitting tower is approximately 180 feet high. On January 31, 1978 the New York City Board of Standards and Appeals essentially approved the implementing application for this facility. On March 17, 1978 the New York City Board of Estimate, after strong adverse representations by the borough president of

Staten Island, community groups, and individuals, reversed the Board of Standards and Appeals and disapproved construction of the microwave tower facility. The basis of the objections was, at least in large part, the conjectures of possible biological harm to the public from microwave radiation.

As a result of the Board of Estimate action, the following telegram was received by the mayor from O.W. Siler, Commandant, United States Coast Guard:

> It has come to my attention that recent action by the City of New York Board of Estimate has forced a halt in construction of vital microwave relay services for the New York vessel traffic service. The Coast Guard is now faced with a minimum three month delay, possibly as much as a twelve month delay, in vessel traffic service operation. The function of the New York vessel traffic service will be similar in basic intent to air traffic control. It will be a vital step forward in Coast Guard efforts to avoid the loss of life, damage to the environment and potential hazards to the public that result from the devastating effects of vessel collisions and groundings. I urge your careful consideration in deliberations regarding these facilities. We are convinced that microwave radiation from Todt Hill, Mariners Harbor and other vessel traffic service microwave installations poses no hazard whatsoever to citizens. . . .

General Summary of Findings and Recommendations

The biological investigations and the clinical and epidemiological observations to date are incomplete and inconclusive in furnishing a firm basis to establish precise quantitative permissible occupational or environmental standards for exposure to microwave and radiofrequency radiation.

However, sufficient data are available to question the 10 mW/cm.^{2} level employed in the United States. Even this current inadequate OSHA standard, originally established by other agencies in 1961, has been in at least one judicial decision considered to be merely advisory rather than statutorily enforceable.[4] Referring to the representative summary of biological investigations tabulated in Table II and Table III, the power-density region between one and 10 10mW/cm.^{2} over a broad spectral region between 10 mHz. and 100 GHz. can produce a variety of biological perturbations. These effects are not necessarily hazardous but some must be viewed as deleterious in the present state of knowledge.

In particular, certain animal experiments at levels of 10 mW/cm.^{2} or below indicate influences on the central nervous system, adverse cellular changes, including mutagenesis, depleted spermatogenesis, behavioral alterations, prenatal impairment of body and brain weight, and blood-brain barrier alterations. Observations in humans, some of which have been challenged by other investigations, include cataract production, subjective psychological complaints, biochemical or hormonal imbalances, and hematological changes.

The evidence indicates an occupational permissible level for sustained working exposures (viz., in excess of 0.1 hours) of 500 μW/cm.^{2}, i.e., about 10% of the approximate midpoint of the 1-10 mW/cm.^{2} potentially hazardous interval. This is a factor of 20 below the current OSHA/ANSI guideline of 10 mW/cm.^{2} Public health prudence, in the absence of more definitive research to the contrary, would dictate that unregulated or uncontrolled areas available to men, women, and children by virtue of residence, recreation, or general public access maintain a microwave/radiofrequency power-density environment not exceeding 10% of the indicated occupational permissible level, or 50 μW/cm.^{2} The maintenance of environmental permissible levels substantially below occupational permissible levels is general practice of governing hazardous factor control in many areas. This reduction recognizes that the public environment is not subject to the same presumed level of biomedical surveillance and detailed health and safety awareness as the occupational workplace.

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THE COMMITTEE ON MAN AND RADIATION: A COMMITMENT TO THE PUBLIC INTEREST*

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VICTOR HUGO in *Les Miserables* wrote of "...a divine and terrible radiance that transfigures the wretched." I would take excessive literary license were I to claim that Hugo foresaw the successful remission of terminal cancer by application of intense radiowaves, yet his words are prophetic of developments in medicine that will enrich if not radically transform the oncologist's practice. In another sense, the terms "divine" and "terrible" are appropriate in that they identify the extremes of professional and public attitudes toward microwave and other radiofrequency electromagnetic radiations. Few will deny the blessings of safer navigation, better communication, and faster transportation fostered by radio waves and their associated electronic technologies, although some have voiced the opinion that these gains might have been won at the expense of the public's well being.

A loss or exchange is involved with every technological advance. Sometimes the loss is personal but difficult to gauge, as when privacy and literacy were curtailed by mass production and widespread use of the telephone and television. Sometimes the loss is more compelling, as in the realization that x-ray diagnosis compromises the lives of some patients while saving the lives of thousands more. Whatever the loss or gain, it is the net advantage or disadvantage that must be weighed. The potential trade-offs associated with man-made emitters of electromagnetic energy are

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therefore legitimately associated with concern for the safety of those who make and of those who use the products of radiofrequency technology. The Committee on Man and Radiation (COMAR) was born of these concerns.

In 1972 Leo Young and Mark Grove, both electrical engineers and members of the Institute of Electrical and Electronic Engineers, observed that no formally constituted body of scientists existed in the United States with a collective expertness in physical, engineering, biological, and medical aspects of nonionizing electromagnetic radiation. In contrast, there were (and are) many public and private assemblies to evaluate effects of ionizing radiations. To fill the void, The Committee on Man and Radiation was established as a voluntary activity of the Technical Activities Board of the Institute, and Mark Grove became its first chairman. From its inception until the present time, the Committee has included both engineers and representatives of the life sciences, including medicine. Representation of public and private, and industrial and academic institutions has been the rule, as has geographical dispersion of members across the North American continent.

Allen Ecker succeeded Mark Grove as chairman in 1974, whom in turn I succeeded in 1977 when Dr. Ecker left Georgia Institute of Technology for a private position. At the present time, the committee comprises more than 30 men and women; names, specialties, and affiliations of members on the 1980 roster are given in the Appendix.

The fundamental charge to the Committee members is to educate. Nominal responsibility is to the international membership of the Institute of Electrical and Electronic Engineers, which numbers more than 190,000 engineers and allied professionals, tens of thousands of whom work in close proximity to radiofrequency waves and are among those most likely to suffer insult from excessive exposure to radiofrequency radiations. Responsibility is also mandated to the public, which, in keeping with the Institute's long history of public service and concern, must be safeguarded from ill effects that might arise from products of the electrical engineering art.

The Committee is not a monolith of opinion. While its members are recruited for excellence as scientists or practitioners, there is no "party line" to which they subscribe. Indeed, on two occasions within the past year I have been involved as a consultant in legal matters in which one or more members of the Committee provided testimony for "the other side."

I recall one incident in which a member of the Committee, a Fellow of the Institute, was surprised to learn that he and I, respectively, had been asked to testify by counsel for plaintiffs and counsel for defendants in a pending suit over a radar installation. But his surprise in no way diminished the candor, commitment, or cooperation that he gave his counsel—or that I gave mine. (As it turned out, we each offered much the same technical advice and, perhaps coincidentally, the suit was dropped before coming to trial.) The Committee is not a monolith of opinion, but a forum in which specialists exchange information and views, a sounding board by which the significance of experimental results are evaluated, and a gathering point around which theory and data, cause and effect, and predictability, probability, and prevention are debated and deliberated.

Committee members respond to their charge to educate in many ways: they participate in meetings of the Institute and of allied engineering societies; they conduct formal courses; they appear on radio and television; they draft position papers; they write letters, reviews, and editorials; they participate in groups that advise the Congress and the executive departments; they support and take part in programs of international scientific exchange; and, of course, they participate in activities of many professional and scientific societies. One example of such participation is the symposium sponsored by the New York Academy of Medicine that was responsible for this special issue of the *Bulletin*; of the 15 working scientists who presented papers, nearly half were members of the Committee. Another example is the January 1980 Annual Meeting of the American Association for the Advancement of Science in San Francisco, which will feature a special symposium on *Microwaves in Biology and Medicine;* the symposium was initiated by and will feature many members of the Committee.

There are many unanswered—and unanswerable—questions about biological effects of radiofrequency radiation; the members of COMAR make no pretense to omniscience and do not hesitate to acknowledge gaps in the current base of biomedical data. On the other hand, the members are quick to recognize that absence of knowledge is not an invitation to pessimistic and precipitous judgment; that hard propositions from scientific study, not loose assertions, are the best guide to policy and action; and that prudence, not ill-advised presumption, must guide the continuing evaluation and revaluation of potential hazards of radiofrequency radiation.

Committee members do take justifiable pride in the collective expertness of their Committee, and consequently disdain the unfounded speculations offered as gospel to the public by apocalyptic expositors who lack critical judgment or scientific credentials. The members' reaction to the unreasoning person and the unreasonable proposition is well in accord with Lord Bertrand Russell's dictum: Let not nonexperts disagree when experts are in agreement.

Experts do not always agree, especially when a scientific book has as many unfinished chapters as that which records the influence of radiofrequency radiations on biological systems. Three issues of particular concern to committee members focus on the unresolved question of the effects of ultra-long-term exposure of human beings to fields that range upward in intensity from 100 $\mu W/cm.^2$ These issues are identified with industrial radiofrequency heaters, thousands of which are being operated in the plastics, leather, and lumber industries by women of childbearing age; with the small civil but relatively larger engineering populations that are exposed to emissions associated with VHF television and FM broadcasts, which are at critical wavelengths with respect to resonant (enhanced) absorption of radiofrequency energy by human beings; and with the proposed solar-powered satellite, which would shower the biosphere with microwaves for decades. A fourth issue arises from the increasing clinical use of radiofrequency diathermy. These deliberate and sometimes life saving exposures to highly intense radiation need much further evaluation for possible adverse sequelae.

The concern for unresolved issues is being addressed with the disclipine that must characterize a credible scientific body. The most pervasive flaws in the arguments of those who perceive biological dangers in weak radiofrequency fields are those of equating effects of x and gamma radiations with those of radiofrequency radiations, of identifying effects of extremely high levels of radiofrequency radiation with those at low levels, of confusing hygienically trivial effects with hazardous effects, and of assuming that the absence of data—as opposed to presence of damning data—implies adverse influences. Discipline is founded upon the insistance that positive, reproducible reports must underlie useful and enforceable propositions about the nature and hazards of radiofrequency waves.

As the sole private body of experts in the United States charged to evaluate biological influences of radiofrequency radiation, the Committee has an important obligation to its parent institution inseparable from that to the public at large. In this connection, I note that few have contributed more to mankind's material progress than the engineer. And few have more concern than the engineer that the wondrous machines of his making serve well and do not injure the larger community of which he is an indispensable and caring member. If this endorsement appears self congratulatory, I hasten to add that, like many members of the Committee, I am not an engineer. My formal training was in experimental psychology and technical philosophy; my professional associations are in academic and investigative medicine. These disciplines do not provide expertness in engineering, but they do promote the capacity to understand engineers—and to comprehend their admirable concern for and contributions to human welfare and progress.

The engineers have long enjoyed a vocation of technical excellence shaped by a compassionate regard for the general public they have been trained to serve. This inseparable technical and social commitment has been and will be the mainspring of activities and judgments by the Committee on Man and Radiation.

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Appendix

1980 Roster of Working Members
Committee on Man and Radiation
Institute of Electrical and Electronic Engineers

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AN OVERVIEW*

MERRIL EISENBUD, SC.D.

Professor of Environmental Medicine
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ONE recalls that ionizing radiations were discovered in 1895 and that the journals of the world began to carry reports of x-ray injury within one year. I believe that all of the effects of ionizing radiation, qualitatively speaking, were discovered long before World War II. Within two years cataracts had been produced in experimental animals exposed to x rays. Within a few more years investigators had discovered the carcinogenic effects. Müller discovered the genetic effects in fruit flies in 1926.

By 1925 we had a small but very definite epidemic of bone cancers among the radium dial painters. The linear relation between dose and response was hypothesized by 1948, arising out of the work of Lee, and the possibility that there might not be a threshold for genetic effects was put forth at the same time. As the result of a rather limited investment in research funds and talent, we went into World War II knowing the essential facts of how to protect people against the effects of ionizing radiation.

A more modest example is the metal beryllium which, by its place in the periodic table, should not be toxic. Yet, by 1947 it became apparent that beryllium workers were dying of lung disease. Whether it was the action of beryllium per se or some organism, as was suggested, that thrived in the presence of beryllium was not known. The clinical features of the disease were not fully understood, and the disease had not been reproduced in experimental animals, but the epidemiology of that disease was investigated and within three months it was possible to set a standard which still exists some 30 years later and has virtually eliminated beryllium disease from the world.

In contrast to that, we have been working with industrial microwaves now for more than 40 years. I honestly did not know how to measure

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microwaves in 1941 when I found myself making x-ray measurements around the first klystrons being produced. I thought that it would be interesting to make some microwave measurements, but everything was classified and I was not a good enough physicist to design my own measuring equipment. So I borrowed a piece of beef from my wife—she would not give it to me in those years of rationing—and put it on the end of a thermocouple and made some measurements around the tubes. During the past 20 years or so there has been a fair amount of experimental work performed as a result of expenditures that total perhaps $40 million. There has also been some epidemiologic work, but we still do not have a consensus as to the medical significance of the various effects that are being observed. It is the judgement of the investigators whose opinion I trust the most that the observed neurophysiological findings are probably not significant. However, there could be some debate on that.

In contrast to the information that was so quickly gathered in the laboratories and clinics about the effects of the ionizing radiations, we still do not have evidence of significant effects of microwave exposure below those levels known to cause injury by heating. I do not think we should take this as a reason to be complacent, but I think that it does provide some degree of assurance that present levels of microwave exposure are not a major hazard.

I know the electronics industry because I watched it grow. I know the medical directors of many large electronics manufacturing companies in the United States. The plants I have seen are modern and well-operated. The companies have progressive personnel policies. The medical directors are among the best we have in this country and, although they have not done formal epidemiologic studies, I have listened to some of their impressions of what they find when they go through the records of their own companies. That they have found no evidence of microwave injuries is reassuring but not conclusive.

The time has come to pull all that information together. I think that we can no longer say that the Bell Labs do not have enough employees to constitute a cohort of adequate size, nor does Raytheon, nor does General Electric, nor does Sylvania. We have to devise a method to aggregate these small groups into a meaningful cohort as the next step following the kind of study that Dr. Charlotte Silverman described this morning.

I think an essential point is that we do not have what the health officers call a condition of imminent peril. We have looked and we cannot find anything. But we know from example after example that we cannot really prove the negative without a more systematic investigation than we have already done. However, it is significant that after 40 years even the cataract, which almost all of us accepted as an article of faith as being at least one effect of microwave exposure, is no longer being unequivocally accepted as such.

I think that those who have been critical of the "microwave establishment" have been misdirecting their attentions and I would prefer to see them play a more constructive role. Mr. Brodeur, the author of *The Zapping of America,* was at the last meeting of the Electromagnetic Radiation Management Advisory Council (ERMAC) and, when it was learned that he was in the audience, he was asked whether he had any suggestions. His response was totally unconstructive. I would like to have seen ERMAC better supported. Some of the agencies have given it credit for helping to increase their budget somewhat but, if one allows for inflation, there is not much more research going on in the country today than there was when ERMAC got started 11 or 12 years ago. That is not because ERMAC has not recommended increased support. It is because we have not had the support of the Congress, the press, or the various public interest groups that seem to find fault with everything but are not particularly constructive.

As recently as May 1978, a report came from the Office of Science and Technology Policy called *A Technical Review of the Biological Effects of Nonionizing Radiation*. I think the contents of this report are probably consistent with almost everything that has been said here. It was a source of considerable satisfaction on the one hand and disappointment on the other that when these people wrote their report they chose to attach the 1971 report of the ERMAC as an appendix. It was very gratifying for us to realize that seven years after we wrote the report, which comprised the first ERMAC recommendations for a comprehensive research program, this group would see fit to add our report as an appendix. At the same time, it was disappointing to think that so little was done in the interim that the recommendations of ERMAC were still applicable seven years later.

I am not completely satisfied that microwaves are not causing trouble somewhere but if they are it is certainly not to the public. How could they be affecting the public unless they were also affecting industrial and military personnel? If we have hundreds of thousands of industrial workers exposed to microwaves at levels 1,000 to 10,000 times what the public is exposed to, then let us look among them for effects. That is the essence of my message to you today.

I think also that we as individuals should not be driven into opposite corners. We have developed terribly defensive attitudes and sensitivities. It is almost a modern form of McCarthyism. Remember that in McCarthy's days it was risky to say anything good about the Russian culture, Russian language, or Russian music. One became a fellow traveller in that way. Nowadays the environmental issues seem to be discussed only in an atmosphere of advocacy. This is too bad.

A couple of things have happened where I think public officials have allowed themselves to be driven into an extreme position, or have perhaps retreated to it too willingly. The first was in Seattle, where three cases of endometrial cancer were reported. Someone requested that the Environmental Protection Agency conduct an epidemiological study because they found a microwave tower in the neighborhood. The agency should have said "Nuts! There is no reason to associate microwaves with endometrial cancer at any level. A cluster of three cases is insignificant. The levels of exposure out there were a fraction of a microwatt. We are not going to do an epidemiological study." But instead they sent a team out, received an enormous amount of publicity, and are planning to do the epidemiological study.

The second problem, here in New York City, originated with the proposed construction on a Staten Island hill of a microwave relay tower with a total power output of 80 watts. William Mumford tells me that the exposure level at the base of the tower would be 1 $\mu W/cm.^2$ and that it would fall off very rapidly. Thirty-six thousand signatures went to the mayor in a petition from the residents of Staten Island to deny the Coast Guard permission to build that tower because it constituted a health hazard. What the Health Department should have done, and would have done in former times, was to tell the petitioners that there was no health hazard. If they did not want the microwave tower in their neighborhood for cosmetic or esthetic reasons they should have argued the problem on that basis without dragging in the health issue. That was not done, and the Health Department, I think, failed in its obligation to the people of the city of New York by allowing that petition to go to the Board of Estimate and allowing that license to be denied.

In conclusion, it is my view, from a somewhat biased position of an unbiased observer, that we can find some assurance in the absence of injuries in 40 years of microwave use. I think we must continue the biological research. If there were no potential microwave health hazard we would want to do the research because it is important in its own right. But above all let us get on with the epidemiologic work. We could, in the next two years, state unequivocally whether or not there is an occupational health hazard from the microwave exposures. If it turns out that there is, we would certainly want to go the next step and look at the public health problem. If there is no occupational health hazard then the public can be assured, simply on the basis that the public exposure is so much lower, that they can accept the benefits of microwaves in its many forms and stop worrying about the hazards.

GENERAL DISCUSSION: SESSION V*

H. JANET HEALER, *moderator*

National Telecommunication and Information Administration
U.S. Department of Commerce
Washington, D.C.

MORIS L. SHORE, Ph.D., HERBERT POLLACK, M.D., Ph.D.,
DANIEL S. GREENBERG, LEONARD R. SOLON, Ph.D.,
EDWARD L. HUNT, AND MERRIL EISENBUD, Sc.D.

DR. NORMAN SIMON (Mount Sinai School of Medicine): Colonel Godden, who left here a little while ago, wanted to present data on the level of microwave radiation in Cape Cod. He points out that at the closest region to the power supply the power density was 0.06 $\mu W/cm.^2$

I thank Dr. Eisenbud very much for adding up all these observations. However, I could discuss ionizing radiation in a little different way and point out that even in 1948 and 1949, after the war, we were irradiating nasopharynges of children who subsequently developed carcinoma of the thyroid. Just before the war Sir Bryan Windeyer saw the first cases of leukemia induced by ionizing radiation, and subsequently this burst forth into what we accept now as radiation leukemogenesis. So I express, in a sense, a little iconoclasm concerning the safety of a medium which is now used after observations over this relatively short period of time and a little doubt concerning the present microwave standards. In the words of Carl Sagan, the absence of evidence is not evidence of absence. As a physician I would like to see more biological data and especially more epidemiological data before establishing a standard. In my years in the field of ionizing radiation, nobody has ever granted a standard of exposure that gets higher after any time interval. It has always lowered with the passage of time. I am a little worried about what ill effects we may uncover through continued research of the type described.

DR. MERRIL EISENBUD: I agree with most of what you say, Dr. Simon, but some day you and I ought to sit down and try to analyze why the

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medical profession was so impervious to the information that was available. I would not allow my children to be fluoroscoped in 1945. Shortly after that, they were treating tonsils with radium implants and most of us in the field of industrial hygiene and health physics would not allow our children to be subjected to that treatment. The industrial hygienists and health physicists seemed to have been 10 or 20 years ahead of the medical practitioners in this regard. The knowledge was there, but somehow it did not get passed on to the physicians.

MISS H. JANET HEALER: It is also important to keep in mind the difference in levels of general population exposures and those in some occupational situations. Also, while epidemiological data on occupational populations can give us valuable information, I do not think we should neglect work on fundamental mechanisms of radiofrequency interaction. We are talking about a very broad range of frequencies, and have every reason to believe that interactions and effects differ across that range. In the case of ionizing radiation, fairly early on there was a known physical hypothesis as to a mechanism of interaction which applies even at very low levels. A single photon or quantum has the potential of altering atomic structures. We have no counterpart of that with radiofrequency radiation.

DR. LEONARD SOLON: Dr. Eisenbud, in a report entitled *A Technical Review of the Biological Effects of Non-Ionizing Radiation* issued by an ad hoc working group of the President's Office of Science and Technology Policy (OSTP), the following statement is made:

> Research during the past five years has led to significant advances both in research methodology and in knowledge of the effects of radiofrequency radiation on living systems. This work has indicated that some biological systems exhibit responses to radiofrequency radiation at exposure intensities that were previously considered to be too low to produce detectable alterations, for example, in the range of 1 to 10 $mW/cm.^2$ But the extent to which radiofrequency radiation-induced perturbations actually compromise living systems has not been determined, nor are the radiofrequency radiation conditions necessary to produce an observed alteration well-defined.

Do you agree with that statement, Dr. Eisenbud?

DR. EISENBUD: Yes.

DR. SOLON: Then, based on that statement, I submit that the Department of Health, Bureau for Radiation Control, of which I am the director,

*Report prepared for the Office of Science and Technology Policy by an ad hoc Working Group, May 15, 1978.

behaved in a singularly responsible manner and, in a public health sense, in the only way possible under the circumstances. If we had been able to cite a federal Environmental Protection Agency standard of 10 mW/cm.^{2} or 1 mW/cm.^{2} or whatever was acceptable in terms of public health, no one would have been more delighted than I. However, there was no federal standard. Therefore, using the range of 1 to 10 mW/cm.^{2} as an approximate threshold for observable effects, and the midpoint of 5 mW or 5,000 μW as an unacceptable environment in which to work, a standard was proposed for permissible occupational levels at 0.5 mW/cm.^{2} with an additional safety factor of 10 (50 μW/cm.^{2}) for a public environmental standard.

Because the Department of Health is supposed to protect the public environment in the City of New York, I do not see how you can make the assertion, Dr. Eisenbud, that the Department neglected its responsibility. If there has been negligence, it is in the federal statutory responsibility which has been inoperative for a period of some decades. Dr. William Mumford observed at the last meeting of Electromagnetic Radiation Management Advisory Council (ERMAC) that at least the New York City Department of Health took action while ERMAC sat for a period, I think, of ten years.

DR. EISENBUD: A moment ago I spoke about your reaction to the proposed construction of a Coast Guard tower, the exposure level from which, at the very base of the tower, would be only 1 μW, not 1 mW, and would fall off very rapidly with distance.

DR. SOLON: I think you misconstrued the character of the assignment given me, which was not to address that tower but to address the general aspects of environmental standards with respect to microwave radiofrequency radiation in the City of New York.

MISS HEALER: Dr. Solon, as one of the coauthors of the OSTP report, I would certainly stand behind the statement you just quoted, which was given careful thought by several people in this room and by others. I think it important, however, to underscore one thing we have heard a lot about in the last two days, i.e., the dosimetric and other considerations which must be taken into account in its interpretation. That statement reads "biological effects," and that is what it means. It refers to various effects which may or may not be harmful, observed for the most part in small laboratory animals at various frequencies but primarily microwaves. To oversimplify a point: a 2,450 MHz. radiation exposure at 10 mW/cm.^{2} or any other level we want to pick is not the same for a rat as it is for a man. So while that statement is true, it must be interpreted in perspective.

Another point I would like to clarify is that ERMAC is an advisory body. We were pioneers, even "pre-Brodeur," in raising a call for something to be done, not because there appeared to be an imminent public health crisis, but more in the sense of preventive medicine. We wanted to be sure that there were no unknown or unintentional harmful effects from the expanding use of radiofrequency radiation. That was the ERMAC's role and we have continued to advocate doing this work in a rational, balanced manner and to call attention to an issue that, in the national scheme of things, is not a number one priority. It is not energy research, not space research, not cancer research. For such issues and priorities our government has a "solution". If it is a large, high national priority area, we form an agency, we write bills, we appropriate large sums of money, and have "crash programs". We have all sorts of ways to deal with those problems. Radiofrequency radiation was little recognized as a matter of concern. We tried to underscore it so that responsible action would be taken.

ERMAC was established as an advisory body at a very high level of government. I find charges of coverup a little difficult to understand when a White House office was willing to accept the recommendation of a group of advisors for increased research and dollars and seek support for it throughout the federal government—in the Congress, with the Office of Management and Budget, throughout the Executive Office, and with the agencies individually. It has been a difficult struggle because this research has to compete with many other important priorities, nationally and within each agency.

However the ERMAC is not a regulatory body. It can recommend and I think would have raised a red flag if it saw urgency in the research it monitors so closely. In my office, every year we document all federal research in both government and university laboratories. We update that information periodically and review it in all kinds of different forums. Other groups, both governmental and nongovernmental, also review this research. Had we seen anything that suggested immediate cause for alarm, we would have pressed for interim standards or controls even without fully adequate information.

It is in occupational situations that we see higher levels of human exposure and we should review those very carefully. True, we have no general population standard and there are some practical difficulties in not having one. However, there is a considerable disparity between levels we find in the general ambient environment and those at which "effects" are observed in laboratory research. Further, if we are to have standards, what are we going to base them on? It is well and good to say we need a standard; the next question is what standard? What do we base it on?

We have discussed differences between Eastern and Western standards and note as much as a thousand-fold difference in occupational protection levels. However, whatever their differences, all standards around the world are based on the concept of average power density.

Some research in the Soviet Union, Eastern Europe, and in this country suggests differences in biological response with different waveforms, e.g., modulated and continuous wave radiation at the same average power density. But nobody in the world today has definitive answers. So, although all today's standards are based on the concept of average power density, this may not be sufficient in itself. Let us be sure that we do not take action that precludes developing the information we need. Let us not settle for quick solutions that we cannot be confident will adequately protect anybody.

Mr. Hunt is sitting in for Dr. Justesen to represent COMAR.

MR. EDWARD L. HUNT: I think that one of the things that Dr. Justesen would have commented on is that great care has to be taken to avoid quick interpretations. They can be grossly erroneous. The OSTP report was carefully reviewed, and recognized the problem of coupling of external energy, i.e., incident energy, to the absorbed energy which produces biological effects. This coupling depends on a number of factors, among them size, and particularly whether or not the size of the exposed human or animal is within a resonant frequency range.

The OSTP report, and the forthcoming American National Standards Institute (ANSI) recommended standard take such factors into account. To act responsibly, any standard-setting group must document such coupling considerations. It would make no difference whether this regulatory activity were for a county, a large city, a state, or the federal government. This is a necessary step in relating incident field measurements to probable biological effects.

I have been an observer of the ERMAC for nearly five years, and yes, they do sit on chairs when they convene. It is an advisory body, and I think it would be extremely irresponsible if it were to play fast and loose by trying, itself, to establish specific standards.

MR. WILLIAM MUMFORD: I have been quoted. What I said at the ERMAC meeting after Dr. Solon had made his presentation and was so unmercifully criticized by members of ERMAC was not what Dr. Solon said, but that Dr. Solon is to be congratulated for having arrived at an exposure standard for the general public. This is something that the United States government has not been able to do during the past 25 years. I did not criticize ERMAC, and I did not mean to criticize the government. I meant to compliment Dr. Solon for arriving at a conclusion I felt was very badly needed for the past 25 years. I hope that this sets the record straight.

DR. LOUIS SLESIN (Natural Resources Defense Council): At the end of his presentation, Dr. Eisenbud asked to look at the workers and to have some more epidemiology. I cannot agree with that more. I was invited to one of the first planning sessions of this conference, and I was told at that time that the purpose of this meeting was to instruct practicing physicians about nonionizing radiation. Yet the working physician has not been told what to look for in terms of possible microwave or nonionizing radiation damage. That is, if a patient came to a physician with symptoms that the physician did not understand, could this in fact be from some kind of overexposure to nonionizing radiation? How could the physician discover whether or not there was an association? That physicians have not had this kind of information from the Academy is a notable omission.

Two federal agencies are noticeably absent from the proceedings. They are the National Institute of Occupational Safety and Health (NIOSH), and the Occupational Safety and Health Administration (OSHA). Neither of these is represented, nor are any affected labor unions. There may be representatives in the audience, but none presented papers. I think it is worth looking at some statistics related to the nature of occupational exposure to nonionizing radiation in the United States.

Mr. Janes showed a slide yesterday that indicated that measured levels of nonionizing radiation have been far in excess of what is known as the ANSI standard, 10 mW/cm.^{2} I think up to 26 times the magnetic field equivalent of the standard was measured on one occasion. These are peak values, I admit, but high values nonetheless. It is worth noting that such levels have been measured in the field, but it does not stop there. As Dr. Solon mentioned, the OSHA standard is not enforceable; it is only a guideline. In fact, below 300 MHz. one can say that the standards are written in the wrong units. A standard should not be expressed in power densities at all. It should be in terms of the electric field and magnetic field components. So we have, at this point, a standard which is not being met, is not enforceable, and is sometimes in the wrong units.

Mr. John Villforth, of the Bureau of Radiological Health, wrote in a letter to Dr. Solon that the Bureau of Radiological Health (BRH) believes the 10 mW standard was set arbitrarily. The scientific data do not support that standard. Further, if one looks at the minutes of the ANSI subcommittee that wrote that standard, one can see that there were two dissents from that standard—one by BRH and one by the Environmental Protection Agency (EPA). Both of these agencies, whose missions are to protect health, said that there should be some caveats in the language of the standard noting that it does not protect the general population. These caveats are not included as part of the standard package.

Who is being exposed? Well, we do not know, but according to NIOSH documents supplied to the Senate hearings in 1977, the numbers go up to 20 million workers. I think that is a high number, but that is the number that NIOSH gave to the Senate hearings. Many of those workers are women of childbearing age. Those women will not feel that radiation when they are exposed to it. The sensation will not be there, so they will not know that they are at risk. In fact, most employees and most employers do not even know they are being exposed to nonionizing radiation.

There is no portable equipment with which to take measurements in the field at this time. The example that was given earlier by Dr. Justesen about the *Globe* reporter not knowing how to calibrate the meter is a good one. The meters that are available to measure in the radiofrequency range are very complex. They are not very portable. One can take them around, but it is very hard to take a good reading.

So we have a very serious omission: this symposium has failed to consider occupational exposure in the United States today. The question which I pose to the members of the program committee is why this problem was not addressed if the objective of this conference was to instruct physicians about such hazards.

DR. EISENBUD: I do not think the microwave field is unique in the difficulties presented when one tries to set a public standard. It so happens that the oldest standard for toxic metal was established by the group that Leonard Solon and I worked with during the late 1940s for the metal beryllium, to which I referred earlier. It was not until last year that a standard was set for lead, about which we have known so much for so many years. Sulfur dioxide oxidant, nitrogen oxide, and carbon monoxide standards were set in the early 1970s. We have an asbestos standard, and there is an attempt to set a benzene standard. I may have omitted one or two, but the point is that with all of the thousands of toxic chemicals that people are exposed to, standards have been issued for only about eight.

The ionizing radiation standards were set in the 1950s as guidelines very much like an ANSI guideline and have not, as far as I know, been issued by the Environmental Protection Agency (EPA) to this day. The National Research Center (NRC) has set a standard only for light water reactors. I remind you that we know far more about each of the environmental agents that I mentioned than we know about microwaves, and have more reason to believe them capable of producing damage to public health. None is nearly so complicated in the biophysical, physical chemical sense as are microwaves.

DR. SLESIN: I am not sure that Dr. Eisenbud has explained why no one at this conference discussed occupational exposure to nonionizing radiation.

MISS HEALER: As I remember the planning session, emphasis was placed on communicating the state of knowledge and issues associated with health effects of microwaves and other radiofrequency radiation to a largely unfamiliar medical audience. In trying to do this, it was generally agreed that it was not desirable to call in the entire federal bureaucracy for recitations. The sense of the physicians and the Academy to the program committee was that they were interested in an overview and not in detailed dissertations on regulatory authorities, jurisdictional disputes, and areas of responsibility of different regulatory agencies. So it was decided to look to John Villforth* of the Department of Health, Education and Welfare's Bureau of Radiological Health, who has been involved for a long time and is highly knowledgeable to represent the matter of standards in general and the activities of all the agencies. I think the activities of these agencies, including OSHA and NIOSH, have been addressed in this symposium.

As illustrated in NTIA's Fifth Summary Report (March 1979) on the federal research program, NIDSH has only a small activity.

A year ago they started a teratogenic research project. They hired a teratologist after considerable struggle. They have a near field synthesizer to simulate the kinds of fields associated with some of the high frequency operations in industry. They have had to justify this research within their

*Mr. Villforth was scheduled to attend but was unable to do so. He sent Dr. Moris Shore as his representative.

own agency by its association with an institute initiative concerning women in the workplace. They have had a very difficult time supporting their radiofrequency/microwave program.

The Institute also surveyed radiofrequency fields and exposures which resulted in some of the information on field strengths that Mr. Janes and others have pointed out, and they are currently attempting to establish an epidemiological study. Additionally, they have published two notices in the Federal Register concerning the development of a criteria document for microwave/radiofrequency radiation (among other factors) and soliciting information. They received no useful information in response to those requests.

They then contracted support to review the literature as a basis for developing a criteria document which will include a recommended occupational standard. I understand it is expected to be issued sometime this summer, but certainly before the end of the year.

DR. SLESIN: My point is that these proceedings should show that substantial exposure to nonionizing radiation is occurring. Practicing physicians should know relevant facts and statistics so that, if confronted with health effects in a patient, he might recognize them as chronic or acute effects of nonionizing radiation.

MR. HUNT: There is a problem of communications, I think, connected with this symposium itself. The symposium is directed to informing physicians of the very kinds of things Dr. Slesin was questioning. What has this symposium told the physician to look for? Let us consider what has been looked for in the past, the history of syndromes or injury. The main problem we face is that there is no clear-cut syndrome to instruct the physician to look for among his patients.

One of the earliest identified injuries, of course, was eye lens opacification, and research has progressed on this. You heard Dr. Carpenter's representation of the current status of that information. It would appear that one must have relatively high levels of exposure to be really concerned about cataracts. And it is not certain whether there is a unique microwave cataract or not.

In the foreign literature we have reports of a neurasthenic syndrome, a very complex, psychiatric category. In this country it is no longer recognized as a syndrome as such, but is treated as a collection of complaints that may or may not be related to each other. These complaints, such as lassitude, loss of libido, and a whole series of others are related, among other things, to age. It might well be that with an aging electronics industry population, complaints of aging are being picked up. And perhaps they are even socially reinforced by designating this work a "hazardous occupation" which brings such advantages as shorter work hours, vacation privileges, and so forth. This might be how that syndrome arose on the Russian scene.

I think the American research community is derelict in investigating this syndrome or the components of it, but perhaps this has been because we do not want to win the Proxmire "Golden Fleece" award by investigating sexual inclinations.

Absence of a clear, obvious injury syndrome is very clear except with exposure to extremely high levels, much higher than we are discussing. It should by now be evident to physicians that there is little or no guidance from science as to a singular, specific kind of effect such as you would find from, for example, cotton dust, zinc, or lead.

We do need to look for things such as effects of partial body exposure. I hear from my colleagues, for example, that one of the crying needs is to get at near field dosimetry solutions to find out how much energy is deposited in various parts of the body so that we can experimentally duplicate exposure circumstances of workers in the sealing industry and so forth. The agency responsible for looking into these things might not have adequate resources for such work but it is a legitimate problem for that agency.

One of the things I fail to find is any suggestion from other than its dosimetric aspects that there is a problem with partial-body exposure circumstance. I have failed to hear any statements from physicians, biologists, or physiologists about what dependent variables they might investigate.

Now again, as to the absence of a syndrome, have there been cogent health complaints? One of the things any regulatory activity should pay attention to is evidence of complaints and the existence of injuries that would warrant the massive cost of federal regulation or compulsory regulation.

MISS HEALER: There was an ANSI activity, which might still be continuing, to try to develop criteria to be used by physicians in examining people exposed to radiofrequency/microwaves. The basic question is what one should look for. And, based on present knowledge and evidence, there has been great difficulty in developing such criteria.

DR. HERBERT POLLACK: I sit on the committee trying to develop criteria for physical examinations and so far we have not come to any resolution of the problem. There just is none. It is not from lack of effort. We have heard a lot about the biological effects as frequency dependent. Industrial frequencies are quite different from communication frequencies and from radar frequencies. To attempt to set up a standard that encompasses all frequencies or to do an epidemiologic study with one frequency and then to transpose findings to another frequency can result in misjudgment. We have to avoid this trap.

MR. RICHARD REIS (Bureau of Medical Devices): Has anyone determined what percentage of change in the overall population exposure could be anticipated from the proposed solar powered satellite and what effect this might have on epidemiology?

MR. NATHANIEL F. BARR (U.S. Department of Energy): The reference design for the solar powered satellite system visualizes that the microwave power that will come down from them will result in 300 gigawatts of electricity. Between 1 and 10% of that microwave power will not land directly on the sites, and therefore will be distributed, not uniformly, but with a graininess, across large areas, actually across the hemisphere. If, however, this energy principally lands on the United States, which will be underneath the satellite, there will be a substantial increase in the average power density experienced by the population of the United States in a relative sense. There is no satellite power system yet in space and there is no antenna design. All of this is going to change and be improved, I am sure.

DR. CHARLOTTE SILVERMAN (Bureau of Radiological Health): A question was raised as to what to tell physicians, what kinds of instructions should come out of this. It seems to me that they can be advised to take very careful occupational histories. Going through the litany of all suspected symptoms and having these in mind as one examines the patient is a rather difficult thing. We have them, but the idea is to find out in a very careful fashion where their patients work and what they do, and get the best detail that they can about their work history. Then use this in connection with symptoms and signs to increase awareness. This, I think, could be one of the instructions for physicians.

MR. HUNT: You are quite right; the physicians should be alert for symptoms that might be related to work conditions or history. There have been two events in which conjectures as to possible syndromes have been made. One, very recently, had to do with video terminals where workers were exposed to images on a video screen. This was thoroughly investigated, and it became evident that, whatever the workers' complaints, it is more likely that, in fact, the video terminal operator exposes his machine to more radiation in the microwave region than he gets back from his terminal. There is no measurable microwave output from the terminal.

Questions still remain as to the health hazard, but not from microwaves as originally conjectured. There must be something else about video terminal work that creates problems for the operators because it is not a microwave problem.

The second conjectured microwave problem occurred some years ago. This had to do with complaints of cardiovascular conditions and heart attacks at an early age for residents of North Karelia, Finland. This was attributed speculatively to Russians beaming microwaves over that region of Northern Finland. This conjecture has even been repeated in a recent government report as though such effects might credibly be attributable to microwave injury. The Finns had not heard about this supposition. Instead, they and other health investigators saw a very high level of cardiac disease and young men dropping dead. This led public health agencies to seek a solution. In about 1971 or 1972 the North Karelian Project was established. Symptoms were viewed as an epidemiologic problem—essentially they had a disease, and began to look for the vectors that produced it. This is the classic idea of epidemiology. It is not like investigating some agent such as microwaves and then searching for a disease to fit.

The North Karelian Project began to investigate such things as dietary habits, smoking, weight, and similar things. They concluded that perhaps smoking and excess fat in the diet might produce these effects. They did this kind of epidemiologic study and then established a local community program where the women in the community became involved. They actually, in fact, changed the dietary habits in this region of the country, and the heart attacks and cardiovascular complaints are apparently being reduced. I have not seen the most recent report of this.

DR. POLLACK: With regard to Mr. Hunt's comments, I would add that the high cardiovascular problems in this area were published by Ansel Keyes 20 years before the Russian over-the-horizon radar was set up.

DR. GEORGE NAGAMATSU (New York Medical College): I am one of the few practicing physicians in this audience and I was attracted by this subject because nonionizing radiation has never been publicized, as far as I know, among our colleagues. I appreciate Dr. Slesin's concern for giving us guidelines, but, as Dr. Silverman noted, the state of the art could only make us alert to the existence of these hazards. That in itself has been a great plus for me.

I am a urologist at New York Medical College in Valhalla, and we are research-minded. I have started to think, when a prostate is removed by transurethral surgery, how much microwave radiation does this fellow get during this very high energy procedure. A certain percentage of these patients after removal of the benign prostate develop cancer of the prostate in the posterior lobe, the part which is not removed during this procedure. Now that I am alerted to this research possibility, I will put one of my residents on this problem, perhaps in a retrospective study and a prospective study.

MR. HUNT: What is the source of the radiation in the operation?

DR. NAGAMATSU: Electrocoagulation.

DR. CARPENTER (Bureau of Radiological Health): First, I reply to Dr. Slesin that it is not at all difficult to measure the electric field strength with the electromagnetic survey meters in existence. They are very portable and I think one could teach someone in five minutes to use it properly.

In considering hazards of microwave radiation, I always in my mind raise the question, is this a transient physiological effect or is it a permanent effect? I do not think we ought to worry about transient physiological effects, some slight changes in the blood picture. One can get changes in the blood picture every day. One can experience physiological changes if someone insults one. One will get a quick flow of adrenalin and then one is physiologically different from what one was, but I do not think we can pass a regulation on that.

Dr. Solon mentioned a series of, he said, physiological changes, among them cataracts, changes in the blood pictures, neurasthenia, and so on. The cataracts are a permanent change, an anatomical change, a histological change that does not go away. Changes in the blood picture may be permanent, and they may be transitory. I do think that when considering regulations one should pay attention to what is more constant and not try to regulate against the transitional or ephemeral.

DR. SOLON: I tried to make the distinction between things that are reversible and those that are clearly irreversible. I reinforce the point made by Dr. Silverman that, for future epidemiologic retrospective studies, a physician should note the occupational environment. Mr. Hunt said we have not much to worry about. As we all know, the Karelian syndrome is all nonsense—I say that ironically—yet the allegations appear to be somehow always dismissed. The fact is that if you begin listing congenital malformations, neurasthenic disorders, abnormal hematology, malignancies, Down's syndrome, cataractogenesis, just to mention a few, one has a spectrum of medical potentiality, although not conclusive or definitive, that should concern the treating physician.

If a patient were exposed in a systematic way to microwave radiation as part of his or her regular activity or occupation, I think that certainly a physician attending this meeting would be delinquent in his responsibilities if he did not carefully identify the potential for microwave radiofrequency occupational effects in the environment as a cause for whatever clinical syndrome or pathology the individual brought in. There may be all kinds of causes. There may be all kinds of situations.

MISS HEALER: The literature will not allow one to rule anything out. That is part of the problem. It contains at least one report of almost every possible effect or symptom one can think of.

MR. HUNT: This is a problem of communication between the scientific community and those that need this information for such things as standard setting. I think every suggestion has to be given a reasonable consideration. For example, there is beginning to be some evidence that the dosimetry has not been very good as yet in the field of teratologic effects and that, when one gets up to levels of whole body heating with microwaves, one can produce teratogenic effects in rats. I think this is to be pursued related to duration of exposures and so forth, but it has to be put in its proper setting. I do not think, at this stage of the game, one should use such observations without proper information to justify a standard.

MR. DAVID E. JANES, JR. (Environmental Protection Agency): As someone who has to wrestle with the question of whether there is a need to set environmental standards, one of the things that one has to examine is what kind of terms to set them in. Based on some of the things said yesterday and in looking at the list of effects, I think we ought to recall that when energy is incident, three things happen. Some is reflected, some is absorbed, and some is transmitted through. This means, at least in an energy absorption sense, that power density is not, at least in our minds now, a very good descriptor of potential hazard.

I am not going to recommend an alternative, but I would point to at least the following consideration: one way to normalize would be to look at the rate of energy absorption in terms of watts per kilogram. If, in doing that, one finds that the whole set of effects is not explained by the rate of energy absorption, then that provides one with a very interesting avenue for going ahead and looking at other mechanisms.

Another thing to be said is that if one uses a single power density number, over the entire frequency range, then at some frequencies one will be 10 times more protected, at other frequencies 100 times more protected, and at still other frequencies 1,000 times more protected than one is at some frequencies.

DR. JOHN OSEPCHUK (Raytheon Company): Dr. Solon, if one is to write a standard, is one to attempt to take into account frequency dependence across the wide range, exposure duration, and many other things that have to be set in a standard?

DR. SOLON: Addressing the spectral uncertainties of the whole range would make a statutory regulatory standard impossible to implement, as you well know and, as a matter of fact, OSHA has not done it. In the ionizing radiation field, we talk about five rems per year, recognizing the whole spectrum of uncertainties and insufficiencies over the spectral range.

It is a little bit of the obfuscation that Mr. Greenberg alluded to when you raise this question. In other words, you are saying that it is really impossible to set a regulatory standard because one must microscopically address each and every portion of the spectrum, and that is just absurd. We cannot do that.

DR. JOHN M. OSEPCHUK: I did not say that it was impossible. I am inviting you to set your standard but take into account these matters. Other groups are attempting to do it.

DR. SOLON: I think that we recognize that if one employs a power density standard, there will be different levels of protection at different spectral intervals, and I see nothing wrong with that in terms of regulatory enforcement.

DR. POLLACK: I would remind you, Dr. Solon, that in the Johns Hopkins study approximately 40 conditions were selected and studied for incidence, both in the Moscow group and in the other Eastern European groups. The incidence of congenital malformations was greater in the non-Moscow group. For the 40 conditions the numbers were essentially similar or greater in the non-Moscow group, except for some things like intestinal parasitism, for which Moscow is indeed famous.

There is another side to this coin. Yesterday you heard some stories about lymphocytes and lymphocytosis being altered by exposure to microwaves. During the course of our work in Moscow we found that a third of the people had an elevated lymphocyte count. This raised a very big red flag about what was going on. Were we finding a microwave hematological effect? We carried out an epidemiological study on the people who had elevated lymphocytes. We found that a third of these people never had any microwave exposure either because they worked in areas at the building where there were no signals or because they were housewives who lived as much as three miles away from the embassy and may only have come to the embassy occasionally. Another group came to the embassy after the screening was put up when the maximum microwave field strength anywhere in the embassy was fractions and fractions of a microwatt. And there was the other group who worked in the areas where they received maximum exposure.

When any of these people came back to the states, within two weeks their lymphocyte counts were reduced to normal. We reviewed the situation and found this. As soon as we instituted water discipline and had people boil their water, within 10 days this whole lymphocyte problem disappeared. We inferred that this was a manifestation of an intestinal infestation. Putting in water discipline eliminated it. Had we not done this we might have said "Good heavens almighty, we have a lymphocyte problem on our hands, produced by microwave exposure." I would make a plea for a study of all other possible causes to make sure that the etiological factor is a real one and not an artifact due to guilt by association.

DR. SOLON: Dr. Pollack, I certainly agree and I in no sense want to detract or withhold my endorsement of the very careful Lilienfeld study of the Moscow workers.

DR. POLLACK: The hematological study I just cited was mine.

DR. SOLON: In fact, considering the tremendous punishment that I have gotten from the industry and, with due apologies, Dr. Eisenbud, the microwave establishment, with my 50 μW/cm.^{2}, if it had turned out that as little as 18 μW/cm.^{2} was deleterious, I would have been devastated. So I appreciate the careful work that has been done and I think it should be continued in the future. I emphasized in my presentation that there is really insufficient information for precise quantitation. However, there is sufficient information that 10,000 μW/cm.^{2} is not an acceptable level in terms of an environmental standard for men, women, and children. It should be a factor of 200 lower.

DR. ELLIOT POSTOW (National Naval Medical Center): I make a plea on behalf of the microwave establishment to those who are not of the establishment that we try to distinguish between emission, exposure, and dose. These are three very vastly different things. At one time we tended to confuse standards in terms of exposure and emission and now we tend to confuse dose and exposure. We in the microwave community must be very careful in our choice of words so that we convey what we really mean. If we are remiss you should question us to insure clarity.

DR. MORIS L. SHORE: Two topics came up earlier on which I want to comment. One had to do with biological effects produced by microwave expsosure and that if transient we might not have to be concerned about them. One of the things that we should explore is whether repetitive insults which individually lead to reversible effects may not, in fact, produce some sort of a lasting problem that becomes apparent only after many, many such insults are administered. Such effects may at such a point cease to be insignificant.

The second point I would make is minor, and it has to do with a comment Dr. Eisenbud made earlier that we should be able in two to three years to look at occupational records and get some real idea as to whether we have, on the basis of some epidemiologic assessment, a problem in the microwave area or not. We do have a rather respectable epidemiologic program; I am impressed that it is very seldom possible to conduct speedy definitive epidemiologic evaluations. Such an evaluation and study would take a great deal of work, a great deal of time, and that assumes that everyone would cooperate with such a venture.

On several occasions in the past we have been interested in following up populations exposed to microwave, notably situations where people were treated with microwave diathermy following dental surgery and we initially encountered cooperation and interest when we approached them. However, as we explained what we were looking for and what our concerns might be with respect to possible cataractogenesis and other effects in man, enthusiasm for the possible study waned and institutions on a number of occasions ceased to use microwave diathermy in the treatment of dental patients.

DR. EISENBUD: You have added to the litany of objections by investigating biologists that I had not thought of this morning, but I know of half a dozen industrial companies now that would make their people available for study if somebody wanted to do it. Zaret, Cleary, and I accumulated records on both exposure and lenticular status as of 1960 or so on some

1,700 people. If we got back to those people 20 years later to find out, not only about their lenticular status, but their general health, I think it would be immensely valuable.

DR. JOHN A. BERGERON (General Electric Company): I would pick up on what Dr. Postow said about distinguishing between emission, exposure, and dose, partly because I think I detected, maybe erroneously, that Dr. Slesin would really like to have a small, hand held meter for all frequencies in all places at all times with an alarm bell on it that reads "hazard." I think the technical message of the panel is to point out that it is very difficult to imagine doing that in near field and far field. And somebody should really point out that that is going to be a very difficult thing to do.

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