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Exposure to Microwaves

Recent experiments on animals with high-intensity 12-cm radiation indicate that a dangerous amount of heat may be generated beneath the surface of living tissue without causing fever or the sensation of pain

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A LARGE number of preliminary experiments conducted with anesthetized laboratory animals indicate that injury by exposure to microwave radiation may occur at relatively low field intensity. It has also been found that pain cannot always be relied upon to warn of a dangerous field.

The most vulnerable parts of the body are those not abundantly supplied with blood. Blood is an effective coolant and acts to distribute heat developed at the site of irradiation, preventing excessive local temperature rise. Certain parts of the body are not effectively cooled by the blood stream. Examples are the lens of the eye and some internal organs such as the gall bladder, urinary bladder and parts of the intestines. When such organs are subjected to microwave irradiation very high local temperatures may result.

Result of Experiments

A series of experiments was performed on rabbits to determine the extent of damage to the eye. These animals were chosen because their eyes closely approximate the size and shape of the human eye. It was found that cataracts were formed upon exposure for 10 minutes at a field intensity of about 3 watts per square centimeter at a wavelength of 12 cm. The cataracts do not become apparent immediately, but develop 3 to 10 days after exposure. Infrared, ultraviolet and x-ray radiations are known to produce painless lenticular changes in human eyes. Apparently, microwave exposure will produce similar results much more rapidly. However, to date no experiments have been performed on humans.

A WARNING—NOT A PRESCRIPTION

The purpose of the authors and editors in presenting this article is to warn workers against the dangers of uncontrolled exposure to high-intensity r-f energy, not to recommend for or against any method of diathermy or any particular frequency for medical treatment. The latter matters are the concern of competent medical specialists, who alone can define the tolerable dosage and method of application in specific cases

Pulsed Power

No experiments have yet been performed to evaluate the relative dangers of pulsed power as compared to continuous power. However, rough calculations of the thermal time constants of typical physiological structures indicate that these are long as compared to the interval between pulses in typical radar sets. Accordingly, it seems reasonable to evaluate the danger from apparatus of this type in terms of average power rather than peak power.

Experiments have been performed at wavelengths other than 12 cm. Preliminary results indicate a radical variation of physiological effects with wavelength. These can be ascribed to variation in loss factor of the body with wavelength.

At longer wavelengths where the loss factor is relatively low the temperature of the whole body is raised, giving rise to artificial fever and to a sensation of warmth but with little danger of tissue damage. At extremely high frequencies the loss factor is relatively high and energy is largely absorbed near the surface. This may cause severe surface burns, but ordinarily the sensation of pain will give ample warning in such cases. At wavelengths in the vicinity of 10 cm, on the other hand, the loss factor is such as to cause the highest temperatures to occur about a cm below the surface in structures not cooled by an abundant flow of blood. Figure 1 illustrates these points.

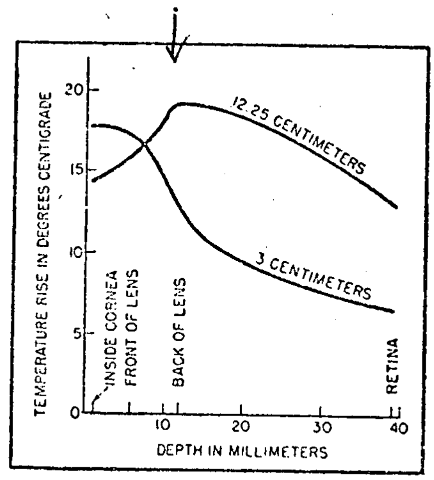


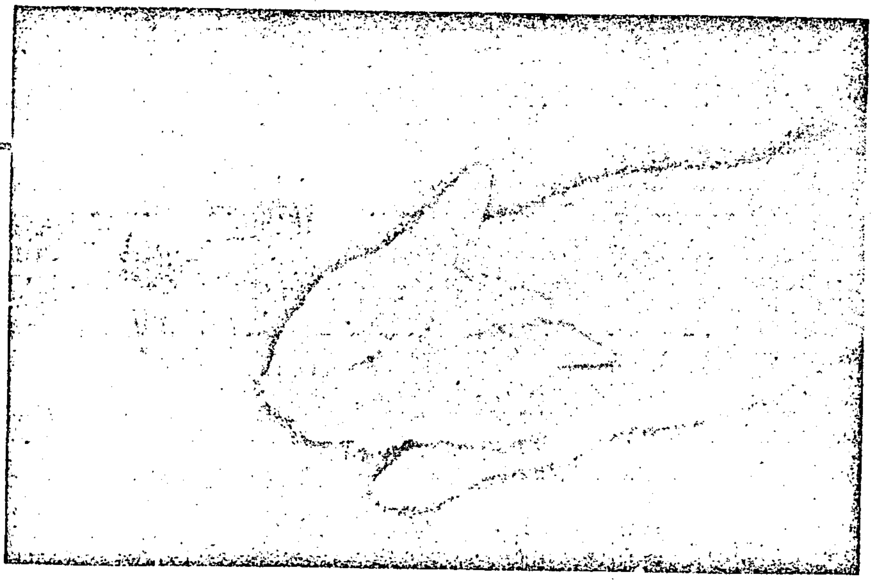
FIG. 1—Experimentally-determined variation of temperature in an excised beef eye exposed to microwave radiation

Technical Explanation

Consider a greatly simplified situation. A plane wave of electromagnetic radiation falls upon an idealized animal, assumed to be a homogeneous dissipative medium. The energy density in the electromagnetic field a distance x below the surface of the animal is

$$E = E_o e^{-\alpha x} \qquad (1)$$

where E_o is the energy density



Anesthetized rabbit being irradiated with 12-centimeter radio waves

(measured in watts per square centimeter) at the surface and α is the attenuation constant of the medium. Since α is the fraction of the energy removed from the beam in one centimeter, the energy transferred to the medium as heat is just α times the energy density at the point in question. This transfer of energy from the beam of electromagnetic radiation to heat in the tissue is assumed to be solely due to dielectric heating. Let us define $H(x)$ as the number of watts per cubic centimeter of heat energy transferred from the beam to the medium. Then

$$H(x) = \alpha E(x) = \alpha E_o e^{-\alpha x} \quad (2)$$

It is well known that the loss factor and hence the attenuation constant of most materials increases with frequency. This is certainly true of water, which makes up the greatest part of most tissues. We can accordingly draw qualitative curves of $E(x)$ and $H(x)$ for our idealized animals at a low and a high frequency. These are shown in Fig. 2A and 2B respectively.

The temperature rise caused by a distribution of heat like that shown in Fig. 2B depends entirely upon the cooling of the medium. In absence of any cooling, the temperature at any point, $T(x)$, will be proportional to the total number of joules of energy that has been put into the medium at the point x. That is

$$T(x) = CH(x)t \quad (3)$$

where C is the thermal capacity per unit volume of the medium and t is the time of exposure. So in this case the shape of the temperature function is the same as that of the heat function.

A part of the body such as the eye, which is free from blood vessels, is cooled mostly by convection from the surface. In this case the temperature of the surface will be maintained at or near room temperature, T_o. Deep in the structure, however, the effect of conductive cooling is negligible and the temperature will vary as in Eq. 3. Figure 2C shows temperature curves for this case.

Findings Are Preliminary

Work to date has merely demonstrated the danger from exposure to microwaves, particularly in the vicinity of 10-cm wavelength. It must be emphasized that no standards of safety have as yet been established; in the meantime, microwave radiation should be treated with the same respect as are other energetic radiations such as X-rays, α-rays and neutrons.

Several previous investigators have failed to find damage due to microwave irradiations. This is probably due to either or both of two causes: the field intensity was not high enough, or the investigators did not wait long enough for latent damage to develop. The field strength known to be dangerous, 3 watts per square centimeter, is not likely to occur except in the immediate vicinity of a powerful transmitter. The area of cross section of a typical 10-cm waveguide is about 28 square centimeters. Accordingly, one must have a total power of about 90 watts to reach the danger level. In free space the energy is much less concentrated, so a much larger total power is required.

Acknowledgments

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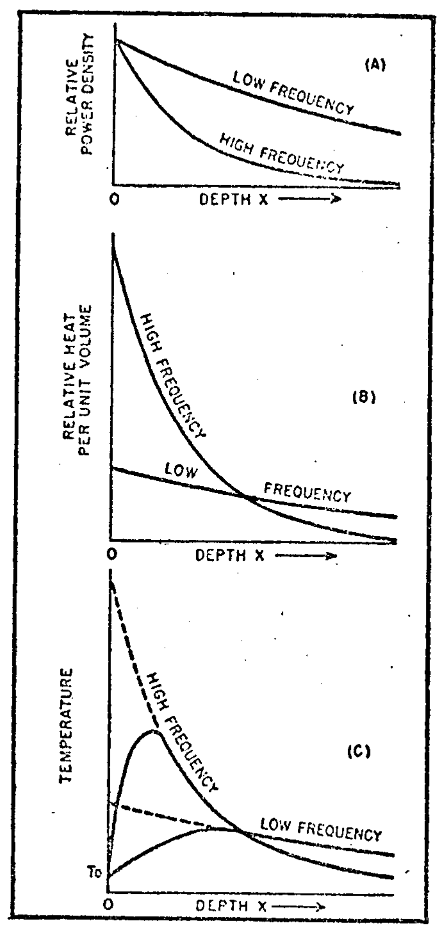

FIG. 2—Variations with depth in an idealized animal. Curves of (C) are calculated, assuming no cooling due to circulation of blood