A REVIEW OF UNITED STATES MICROWAVE EXPOSURE CRITERIA

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INTRODUCTION

Since the early 1940's the development and use of higher powered electronic equipment emitting electromagnetic energy in the microwave region has increased considerably. Although definitive boundaries for the microwave region have not been established, the United States of America Standards Institute defines this region as that portion of the electromagnetic spectrum encompassed by frequencies of 10 to 100,000 megahertz (MHz).[1] This wide range of frequencies serves such uses as television channels, radio broadcast bands, and commercial and military radar. Microwave energy is also used to dry thermo-setting glues used in plywood, to dry chemical and biological samples, to cook or heat foods in microwave ovens, and as a medical application in diathermy and microthermy. The frequencies available for industrial, scientific, and medical applications are set forth in appropriate federal communication regulations.[2]

Biological effects resulting from microwave exposures are primarily a thermal response produced by the absorption of the energy and its conversion to heat. Certain areas of the body, which cannot dissipate heat rapidly, are more susceptible to thermal injury from microwave energy. Of special interest are the lens of the eye, where exposure may result in the production of cataracts,[3] and the reproductive

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organs, in that temporary sterility or degenerative changes have been reported in exposures involving research animals and man.[4,5]

The amount of heat generated in the tissues is primarily a function of the strength of the microwave field [that is, the average power flow per unit area measured in milliwatts per square centimeter (mw/cm^2)], the length of time the area is exposed, and the type of tissue exposed. The type of tissue exposed is, in part, determined by the depth of penetration of the microwave energy, which is a function of the frequency of the energy. The lower the frequency, the greater the depth of penetration into the body. Thus, the range of frequencies from 150 to 10,000 MHz is of primary concern in evaluating potential hazards to microwave exposures.

MICROWAVE CRITERIA

Although many different organizations have promulgated or adopted microwave exposure criteria,[6,7,8] the following four standards are representative of the various exposure control limits employed in the United States in the past 10 years.

Tri-Service Conference - 1957

(5)

The first microwave exposure standard to gain widespread usage, and to be considered by segments of the U.S. Government, was presented in July, 1957, at a Tri-Service (U.S. Army, Navy, and Air Force) Conference on the Biological Hazards of Microwave Radiation.[9]

Information presented at this Conference was based on observations and tests at random frequencies and at differing power density levels performed by various investigators. It was the opinion of those participating in the Conference that there were not sufficient data to determine safe exposure levels for each frequency, or ranges of frequencies, within the microwave region; therefore, a level of 10 mw/cm^2 was selected for all frequencies. The U.S. Air Force in adopting this exposure level in May, 1958, applied it to the frequency range of from 300 to 30,000 MHz,[10] and established it as a maximum permissible exposure level, which could not be exceeded. The only factor considered in this criterion is the power density level. Such factors as time of exposure, ambient environmental

temperatures that could have an increased or decreased effect on the body's thermal response, the frequency of the microwave energy, effects of multi-frequency exposures, differing sensitivity of various body organs, and effect of air currents on cooling the body are not considered, although they are all recognized as factors that might affect biological response.

Bell Telephone Laboratories - 1960

The Bell Telephone Laboratories reviewed the data concerning the biological effects of microwaves and qualified the military's maximum exposure level of 10 mw/cm^2 to establish in 1960 the following criteria:[11]

"1) Power levels in excess of 10 mw/cm^2 are potentially hazardous and personnel must not be permitted to enter areas where major parts of the body may be exposed to such levels.

2) Power levels between 1 and 10 mw/cm^2 are to be considered safe only for incidental, occasional or casual exposure, but are not permissible for extended exposure.

3) Power levels under 1 mw/cm^2 are safe for indefinitely prolonged exposure."

These criteria were based on data that indicated the formation of cataracts at power density levels of 100 mw/cm^2 and on the lethal effect of 50 mw/cm^2 on dogs, rabbits, and rats with only a 40% absorption of incident energy.

U.S. Army/Air Force Standard - 1964 and 1965

In 1964, the U.S. Air Force established additional microwave exposure criteria which began moving away from the concept of a maximum permissible exposure limit to that of a time-weighted average.[12] In the case of pulsed radar systems, the time on, time off, could be averaged if the power density did not exceed 100 mw/cm^2.

In 1965, the U.S. Army and Air Force developed an exposure standard[13] which permitted, under certain conditions, personnel exposures to microwave energy in excess of 10 mw/cm^2. This standard was the first to relate completely the

individual's exposure time to the incident power density. The two parameters are related by the formula:

$$Tp = \frac{6000}{W^2},$$

where Tp is permissible exposure time in minutes during any 1-hour period and W is power density that the worker is exposed to in mw/cm^2. This standard is applicable between exposure levels of 10 and 100 mw/cm^2. At an exposure level of 10 mw/cm^2 the allowable exposure time is 60 minutes per hour, or continuously, but at 100 mw/cm^2 the allowable exposure time is 0.6 minutes per hour. In actual applications, the standard states "It is not feasible to control limited exposures of less than 2 minutes, and consequently this formula should not be applied to intensities over 55 mw/cm^2."

If workers are exposed to power densities greater than 10 mw/cm^2, this criterion requires that they receive specific preplacement and periodic medical examinations. The medical surveillance program should include a routine physical examination and a comprehensive opthalmological examination that includes an evaluation of ocular motility, media and fundus, and corrected visual acuity for near and far vision and a slit-lamp examination of the lens with the pupil widely dilated.

United States of America Standard - C-95.1. 1966

10

The United States of America Standards Institute (USASI) in November, 1966, developed a standard entitled "Safety Level of Electromagnetic Radiation with Respect to Personnel."[1] This standard sets the protection guide at 10 mw/cm^2, as averaged over any possible 0.1 hour period. This standard is based on a power density of 10 mw/cm^2 for exposure times greater than 0.1 hour, and on an energy density of 1 milliwatt hour per square centimeter (mwh/cm^2) for periods less than 0.1 hour. The energy-density concept is a time weighted exposure criterion by which the allowable exposure time in hours per 0.1 hour can be determined by

dividing 1 mwh/cm^2 by the incident power density, expressed in mw/cm^2. Thus for a power density of 60 mw/cm^2, the allowable exposure time (ET) is:

$$ET = \frac{1 \text{ mwh/cm}^2}{60 \text{ mw/cm}^2} = \frac{1}{60} \text{ hr, or}$$

1 minute per 0.1 hour.

In addition to considering exposure time, the USASI standard attempts to consider environmental factors that may affect biological response. The USASI standard guide numbers are applicable for moderate environments; however, "Under conditions of moderate to severe heat stress the guide number given should be appropriately reduced. Under conditions of intense cold, higher guide numbers may also be appropriate after careful consideration is given to the individual situation." The standard also indicates that exposures to microwave energies "characterized by a power level tenfold smaller will not result in any noticeable effect on mankind."

SUMMARY

Comparison of USASI & AF (11).

A review of microwave exposure criteria used in the United States in the past 10 years, indicates a general acceptance of a power density exposure level of 10 mw/cm^2. The first standards developed considered the 10 mw/cm^2 value to be a maximum permissible level which should not be exceeded. These standards considered only the power density level of the microwave energy and did not consider other factors affecting biological response such as multi-frequency exposures, time of exposure, frequency of the microwave energy, and environmental factors that might affect the temperature of the body or its cooling capacity. Although early research work on the biological effects of microwaves was conducted at frequencies normally used with radar, modern industrial, medical, and scientific equipment to a large extent, operate in these same regions. For example, microwave ovens and some medical diathermy equipment operate at 2450 MHz, which is close to the "S-band" of radar.

The two latest exposure criteria, which have been developed since 1965, permit exposures to power densities in excess of 10 mw/cm^2; however, the duration of such exposure is limited. In applying the concept of a time-weighted exposure the health specialist must consider how far the dose-time relationship can be extrapolated. The biological response to extremely high microwave power densities, even though such exposure may be for a very short time period, must be considered. The effects of severe heat stress or intense cold on the body's cooling capacity are noted in the latest standard, although definitive recommendations for applying the concepts are not provided. Future standards should reflect environmental stress as well as other factors found to affect the biological response to microwave energy.

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