Draft (1/77)
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Physical Agent: Radiofrequency

In recent years, the increased use of radiofrequency radiation in communications, navigational technology, medical diathermy, manufacturing industries, and microwave ovens has raised the concern regarding potential biological effects and health hazards of the exposed occupational and general populations. Investigators, mainly in the United States and Eastern European countries, have reported biologic effects in human and animals resulting from exposure of radiofrequency radiation. Various safety and health standards and protective measures for exposure to radiofrequency were established due to the differences in research approach finishing and interpretations (1).

Definition of Radiofrequency

Radiofrequency consists of the portion of the non-ionizing electromagnetic spectrum from 0.03 megahertz (MHz) to 300 gigahertz (GHz) (2). Microwaves are generally defined to be within the frequency range of 100 MHz to 300 GHz (2,3).

Typical sources of longwavelength frequency (0.03 - 100 MHz) energy are electronic oscillators (3). The sources of microwave energy are klystrons, magnetrons, oscillators and semiconductor transmitting devices (IMPATT diodes) (3). Radio waves propagate in a vacuum or through a number of dielectric media, i.e., air, water and tissue (2). The energy, when transmitted, is categorized into two discrete modes known as continuous wave and pulsed (2).

Nature of the Hazard

The amount of power emitted by a radiofrequency source and the amount of energy absorbed by tissue is usually measured in watts per unit area,

i.e., W/cm^2 (4). The amount of energy absorbed depends upon the electrical properties of the tissues, especially their dielectric constants and conductivity (5,6). Those biologic tissues which have a high water content will absorb relatively greater amounts of radiation energy than tissues with low water content, such as fat (5). The greater the frequency of the radiation, the less is its depth of penetration, i.e., frequencies in the 10 GHz range or higher are unable to penetrate beyond the skin, whereas those of less than 150 MHz frequency pass through the body with very little loss of energy (6).

The thermal effects are produced by conversion of the radiation energy into heat. Body temperature increase during exposure to radiation depends on 1) the frequency of radiation; 2) duration of exposure; 3) the intensity of field strength, 4) the thickness of skin and subcutaneous tissue; 5) the specific area of the body exposed; and 6) the thermal regulatory capacity or the efficiency of heat elimination (2).

Biologic Effects on Humans and Animals

Low Radiofrequency Radiation (0.03 MHz - 100 MHz)

The biologic effects of low radiofrequency ($\lesssim$ 30 MHz) have been reported by very few researchers (7,8). Bollinger conducted a short term (1 hour) biomedical study of the exposure of monkeys of low frequency radiofrequency radiation at 10.5, 19.3 and 26.6 MHz. No biological effects were observed at power density of 100 to 200 mW/cm^2 under these experimental conditions (9). Frey reported, at the relative low average power, individuals exposed to the radar radiation resulted in acoustic response (10). Studies by Guy et al and Sommer et al presented the explanations for this observation (11,12). The acoustic response is due to the stimulation of the cochlea through the electromechanical field forces by air on bone conduction.

Biologic Effects on Humans

Microwave Radiation (100MHz to 300 GHz)

Investigators in the Soviet Union reported studies of occupational workers exposed to microwave power density below 10 mW/cm^2. The findings revealed the reversible functional changes in the nervous, cardiovascular and blood systems which lead to a characteristic complex of symptoms (13,14). In reproduction system, in Rumania, a survey was reported of workers exposed to power densities of 10-100 mW/cm^2. In 31 workers studied, 70 percent of workers were found with decreased sex function and spermatogenesis (15).

Microwaves have been shown to cause cataracts in experimental animals (16). In 1948, Hirsch and Parkers noted cataracts in a microwave generator worker exposed to 1.3 - 3 GHz radiation at power densities exceeding 100 mW/cm^2 at times, for a total of 2 hours during 3 days (17). Zaret reported selected cases of microwave cataracts in man (18). A microwave researcher was exposed to an average power density of 500 mW/cm^2, with peaks as high as 4 W/cm^2 over a period of 3 to 4 weeks, exposures lasted from a few seconds to 2 minutes. A cataract developed in one exposed eye (18). From chronic low dose exposure of microwave radiation, a radar engineer was reported developing cataracts after a maximum exposure of 1 mW/cm^2 over a period of 18 months. Approximately 20 years intervened between the exposure and the appearance of cataracts (18).

Many investigators reviewed the reports of microwave induced cataracts in man and concluded that the detection of cataract coincide only accidently in time with the exposure to microwave and, it might be due to other causes such as uveitis or congenital clouding (2,17,19).

Microwave radiation effects on hematopoietc tissue and blood system of experimental animals have been studied extensively. However, few researches were reported for microwave induced hematologic changes in man, because the durations and field intensities of exposure are not easily to be measured. In 1945, Lidman and Cohn reported ureticulocytosis has been noted in some radar workers (20). In 1960, Sokolov and Ariyevich noted changes in reticulocytes in radar workers who were exposed to high frequency of microwave radiation (21). In 1966, Baranski and Ezerski studied a group of people occupationally exposed to microwaves. They found changes in leukocytes in persons exposed to high irradiation for more than 5 years (21).

Biologic Effects on Animals

Carpenter and coworkers reported radiation of microwave at 2450 MHz pulsed or continuous waves can cause lenticular opacification (16).

More information will be provided on biological effects on animal.

Safety Standards

The current federal standard (CFR 1910.97) for electromagnetic radiation is based on American National Standards Institute standard of 1966 (ANSI C95.1-1966) entitled " Safety Level of Electromagnetic Radiation with Respect to Personnel." For normal environmental conditions and for incident electromagnetic energy of frequencies from 10 MHz to 100 GHz, the radiation protection guide is 10 mW/cm^2 as averaged over any possible 0.1 hour period, i.e. power density of 10 mW/cm^2 for periods of 0.1-hour or more; and energy density of 1 milliwatt-hour per centimeter square (mWh/cm^2) during any 0.1-hour period. This guide applies whether the radiation is continuous or intermittent.

In 1974, the American National Standards Institute published an updated "Safety Level of Electromagnetic Radiation with Respect to Personnel" (ANSI C95.1-1974). For normal environmental conditions and for incident electromagnetic energy of frequencies from 10 MHz to 100 GHz, the radiation protection guide is 10 mW/cm^2, and the equivalent free-space electric and magnetic field strengths are approximately 200 volts per meter root mean square (V/m RMS) and 0.5 ampere per meter root mean square (A/m RMS), respectively. For modulated fields, the power density and the squares of the field strengths are averaged over any 0.1 hour period; none of the following levels should be exceeded as averaged over any 0.1 hour period. Mean Squared Electric Field Strength: 40,000 V^2/m^2; Mean Squared Magnetic Field Strength: 0.25 A^2/m^2; Power Density: 10 mW/cm^2; Energy Density: 1 mWh/cm^2. This guide applies whether the radiation is continuous or intermittent. The recommendations are made to prevent possible harmful

effects to humans resulting from exposure to electromagnetic (EM) radiation in frequencies from 10 MHz to 100 GHz. They apply to all radiation originating from radio stations, radar equipment, and other possible sources of electromagnetic radiation such as that used for communications, radionavigation and industrial and scientific purposes.. This standard is not intended to apply to the deliberate exposure of patients for medical procedures or for therapeutic purposes.

In 1976, the American Conference of Governmental Industrial Hygienists (ACGIH) published threshold limit values (TLV's) for microwave energy in the frequency range of 100 MHz to 100 GHz (31). The TLV for occupational microwave exposure where power densities are known and exposure time is controlled is as follows: 1) for average power density levels up to but not exceeding 10 mW/cm^2, total exposure time shall be limited to an 8-hour workday (continuous exposure); 2) for average power density levels from 10 mW/cm^2 up to but not exceeding 24 mW/cm^2, total exposure time shall be limited to not more than 10 minutes for any 60 minute period during an 8-hour workday (intermittent exposure); 3) for average power density levels in excess of 25 mW/cm^2, exposure is not permissable. In addition, for repetitively pulsed sources the average power density may be calculated by multiplying the peak power density by the duty cycle. The duty cycle is equal to pulsed duration in seconds times the pulse repetition rate.

The Notice of Intended Change for TLV for 1976 included microwave energy (31). These TLV's refer to microwave energy in the frequency range of 300 MHz to 300 GHz. The TLV for occupational exposure to microwave energy, where power density or field intensity is known and exposure time is controlled, is as follows: 1) for exposure to continuous wave (CW)

sources, the power density level shall not exceed 10 mW/cm^2 for continuous exposure, and the total exposure time should be limited to an 8-hour workday, at 10 mW/cm^2, the power density is approximately equivalent to free-space magnetic field strength of 0.5 A/m RMS; 2) exposures to CW power density levels greater than 10 mW/cm^2 are permissible up to a maximum of 25 mW/cm^2 based upon an average energy density of 1 mWh/cm^2 averaged over any 0.1 hour period; 3) for repetitively pulsed microwave sources, the average field strength or power density is calculated by multiplying the peak-pulse value by the duty cycle. The duty cycle is equal to the pulse duration in seconds times the pulse repetition rate in Hertz. Exposure during an 8-hour workday shall not exceed the following values which are average over any 0.1 hour period: Power Density - 10 mW/cm^2; Energy Density - 1 mWh/cm^2; Mean Squared Electric Field Strength - 40,000 V^2/m^2; and Mean Squared Magnetic Field Strength - 0.25 A^2/m^2; 4) exposure is not permissible in CW or repetitively pulsed fields with an average density in excess of 25 mW/cm^2 or approximate equivalent free-space field strength of 300 V/m or 0.75 A/m.

Great Britain adopted the 10 mW/cm^2 standard for radio-frequency radiation exposures for the general public as well as the military and industry (32). In Sweden, in 1961, the recommended maximum permissible intensity "within areas where personnel are occasionally to be found is 10 mW/cm^2 for all occurring frequencies" (33). The 10 mW/cm^2 standard is also accepted in the Federal Repulic of Germany and France as the maximum safe level (34,35).

In the USSR, the microwave personnel exposure standards, promulgated in 1959 by the USSR Ministry of Health, specify a maximum safe exposure for

an unlimited period of time of 0.01 in W/cm^2; 0.1 mW/cm^2 exposure is permitted for a period of 2 hours in a 24-hour period; and up to 1 mW/cm^2 is permitted for 20 minutes in a 24-hour period (36).

In 1972, Poland established the new microwave personnel exposure standards (37). Michaelson summerarized the new Polish standards and standards of countries mentioned above in Advisory Group for Aerospace Research and Development (AGARD) Lecture, 1975 (38) (Table I).

TABLE I

Personnel Exposure Standards for Microwaves

Maximum Permissible Power Density (mW/cm^2)	Frequency (MHz)	Country or Agency	Specifications
10	10-100,000	U.S.*	
		ANSI	1 mWh/cm^2, 24h
		NIOSH	8 h workday
	100-100,000	ACGIH	10 mW/cm^2 TLV - 8 h 10-25 mW/cm^2, 10 min/h 25 mW/cm^2 - ceiling value
	300-300,000	Army/Air Force	10-55 mW/cm^2 min = $6000/(mW/cm^2)^2$
1	300-300,000	Poland	0.2 mW/cm^2-10 mW/cm^2 (8 h - 11.5 s) (SF)**
			1.0 mW/cm^2-10 mW/cm^2 (8 h - 4.8 min) (NSF)
		USSR***	15-20 min/day
0.1		Poland	0.2 mW/cm^2, 8 h (SF) 24 h (NSF)
		USSR	2-3 h/day
0.025		Czechoslovakia	8 h (CW)
0.01		Poland	24 h (SF)
		USSR	8 h
		Czechoslovakia	8 h (pulsed)

*Also with slight modification - Canada, United Kingdom, German Federal Republic, Netherlands, France, Sweden.

**SF = stationary field (hr = $32/W/m^2$); NSF = nonstationary field (hr = $800/W/m^2$.

***MPE x 10 for exposure to movable beam or antenna.

From reference 38.

Occupations potentially associated with radiofrequency and microwave radiation exposures include the following (13,30):

Air crewmen

Drug sterilizers

Food sterilizers

Furniture veneering operators

Maser operator (microwave amplification by stimulated emission of radiation)

Metal welders

Microwave radiation generating workers

Microwave diathermy operators

Microwave oven maintenance workers

Microwave radiation testing technicians

Plastic welders

Radar mechanics

Radar operators

Radar testing technicians

Radio transmission operators

Television transmission operators

Tempering steel workers

According to the National Occupational Hazard Survey of the National Institute of Occupational Safety and Health, 1976, the estimated occupational exposure is 10,000 to 50,000 for longwavelength radiofrequency radiation, and 5,000 to 10,000 for microwave radiation.

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