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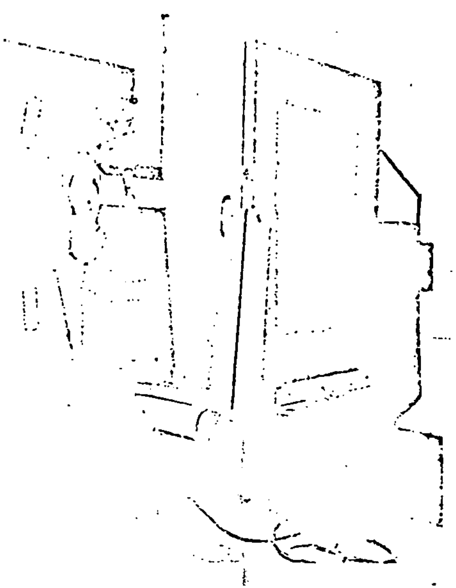

Occupational Aspects of Non-Ionizing Radiant Energy

Exposure - Thresholds and Standards

Are your workers exposed to non-ionizing radiant energy?

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"...potential hazards to the individual..."

The last quarter century has seen a marked development and increased utilization of equipment and devices for military, industrial, consumer use, entertainment, and medical applications that emit a large variety of non-ionizing radiant energies. These include ultraviolet, infrared, visible light, microwaves, and radio-frequency waves that are classified as electromagnetic waves.

Electromagnetic energies at certain frequencies, power levels and exposure durations can produce biological effects or injury, depending on multiple physical and biological variables. There is a need to set limits on the amount of exposure to radiant energies individuals can accept with safety.

Setting protection standards, however, is a very complicated process. Protection standards are the results of empirical approaches to various problems reflecting current qualitative and quantitative knowledge. A numerical value for a standard of effect implies a knowledge of the effect produced at a given level of stress, and that both effect and stress are measurable. One problem is the definition of what an "effect" is and whether it can ultimately be shown to modify man's "way of life" or produce patho-physiologic consequences.

It is important to maintain a proper perspective and realistically assess the biomedical effects of these radiant energies so that the worker or general public will not be unduly exposed. But, at the same time, research, development and beneficial utilization of these energies should not be hampered or restricted by an undue concern for effects which may be non-existent or minimal in comparison to other environmental hazards. The author calls for research aimed at creating credible knowledge and data that can stand against the pressure of legal challenge as well as the bias of special interest.

With passage in the United States of the Radiation Control for Health and Safety Act of 1968 (PL-90-602) and the Occupational Safety and Health Act of 1970 (OSHA), a resurgence of interest in the biologic effects of exposure to electromagnetic radiation has occurred.

OSHA provides broad authority to the Department of Labor and the Department of Health, Education, and Welfare. Among their major responsibilities under OSHA is developing regulations requiring employers to maintain accurate records and reports concerning work-related injury, illness, and death, and employee exposure to potentially toxic substances including physical agents (among which are radiant energies). These agencies must also develop criteria for dealing with toxic materials and harmful physical agents, indicating safe exposure levels for workers over various periods of time.

Produce biologic effects

Many electromagnetic waves at certain frequencies, power levels and exposure durations produce biological effects or injury, depending on multiple physical and biological variables. Although equipment which utilize or emit electromagnetic waves provides immeasurable benefits to mankind, it may also create potential hazards to the individual through uncontrolled and excessive radiation emissions.

Consequently, questions are being raised:

1. How serious are these problems, what are their dimensions, and what acute or chronic effects on the human body may be involved?
2. How adequate is our present knowledge about the personnel hazards of these radiant energies?
3. How can exposure be reduced?
4. How can better regulation be obtained to reduce exposure?

Some guidelines do exist

For the general population and those persons exposed or with potential for exposure to these radiations in the course of their occupations, personnel-exposure guidelines and some product-emission standards have been promulgated. These are for the most part based on the philosophy of maximum permissible exposure and threshold for reversible or irreversible damage to "critical" biological structures.

Personnel protection guides or exposure standards are usually those established by the American National Standards Institute (ANSI), American Conference of Governmental Industrial Hygienists (ACGIH), or Department of Defense. Some industrial organizations have standards of their own which may be modifications of the national standards.

In discussing occupational aspects and hazards of non-ionizing radiant energy exposure, it is essential to carefully distinguish between product-emission standards and personnel-exposure standards and how they relate to occupational health.

Control man-made radiation

The Radiation Control for Health and Safety Act requires the Secretary of Health, Education and Welfare to prescribe performance standards to control man-made radiation from electronic products, both those of USA origin and imported products, if he determines that such standards are necessary for the protection of public health and safety.

An electronic product, under the Radiation Control Act, is any product that uses an electronic circuit and generates ionizing or non-ionizing radiation or sound waves.

Once a standard is established for a class of products, the manufacturer must meet the standard or he cannot market the product. If he does market a product which seems to meet the standard, and if it is later determined to violate the standard, or if it is defective in terms of his own standard, then he may be required to replace, repair, or refund the purchase price of the product.

Any manufactured or assembled product is covered by the Act if it emits radiation and contains an electronic circuit or functions as part of an electronic circuit. The Secretary has delegated to the Bureau of Radiological Health (BRH) responsibility for day-to-day administration of the Act.

Since the BRH was assigned to the Food and Drug Administration (FDA) by directive of the Secretary of Health, Education, and Welfare, FDA thus has become responsible for reducing unnecessary human exposure to

TABLE 1

Protection Guides and Standards for Non-Ionizing Radiant Energies

Energy	Wave length	Guide Number	Duration of Exposure	Comments
Ultraviolet	200-315 nm	$3\ mJ/cm^2 - 1\ J/cm^2$	8 hr	radiation incident on skin or eye
		$(3\ mJ/cm^2 - 1\ J/cm^2)$*	10^{-3}-$3x10^4$ sec	direct ocular or skin exposure
Visible	400-700 nm	$(5x10^{-7}\ J/cm^2)$	10^{-9}-$1.8x10^{-5}$ sec	direct ocular exposure
		$(2x10^{-2}\ J/cm^2)$	10^{-9}-10^{-7} sec	skin exposure
Infrared	800-10^5 nm	7.6 J/cm^2	- - -	corneal damage
		10.8 J/cm^2	- - -	corneal dose causing iris damage
		1.0 J/cm^2	- - -	corneal dose causing retinal damage
		$(10^{-4}\ W/cm^2$-$5x10^{-4}\ W/cm^2)$	10^2-$3x10^4$ sec	direct ocular exposure
		$(0.5\ W/cm^2)$	10-$3x10^4$ sec	skin exposure
Microwave	3 mm-100 cm	10 mW/cm^2	continuous	whole body (higher power permitted for localized exposure)
		25 mW/cm^2	10 min during any 60 min period	
		1-5 mW/cm^2 at 5 cm from external surface	continuous	microwave oven pdt. emission standard
Radiofrequency	1 m-1000 m	0.3 mA/cm^2-1mA/cm^2 1000 V/m	continuous	whole body

* (   ) for coherent sources—laser

man-made radiation in the use of electronic products.

Need for unifying concept

A summary of the various guidelines and standards are shown in Table I. In spite of the fact that this compiliation is simplified and many details are omitted, it does indicate the complexity and variety of protection guides.

ULTRAVIOLET (UV)

For UV exposure, the critical organs are the skin and eyes, resulting in erythema of the skin and skin cancer, rapid skin aging, photosensitization, and keratoconjunctivitis. In 1948, the Council on Physical Medicine of the American Medical Association issued criteria for safe exposure to radiant energy from germicidal lamps (2)*. This group recommended for the primarily used wavelength, 253.7 nm, exposures should not exceed 0.5 μW/cm^2 for periods of 7 hours or less, nor 0.1 μW/cm^2 in the case of continuous exposure.

The American Conference of Governmental Industrial Hygienists (ACGIH) has also proposed threshold limit values (TLV) for ultraviolet radiation. (1) The TLV for occupational exposure to ultraviolet radiation incident upon skin or eye where irradiance values are known and exposure time is controlled are as follows:

1. For the near ultraviolet spectral region (320 to 400 nm) total irradiance incident upon the unprotected skin or eye should not exceed 1 mW/cm^2 for periods greater than 10^3 seconds (approximately 16 minutes) and for exposure times less than 10^3 seconds, should not exceed 1 J/cm^2.
2. For the actinic ultraviolet spectral region (200-315 nm), radiant exposure incident upon the unprotected skin or eye should not exceed the level of 100 mJ/cm^2 for 200 nm to 1000 mJ/cm^2 for 315 nm wavelengths within an 8-hour period. Occupations potentially associated with UV radiation exposure are listed in Table II.

TABLE II.

Occupations Potentially Associated with Ultraviolet Radiation Exposure*

Aircraft workers
Barbers
Bath attendants
Brick masons
Burners, metal
Cattlemen
Construction workers
Cutters, metal
Drug makers
Electricians
Farmers
Fishermen
Food irradiators
Foundry workers
Furnace workers
Gardeners
Gas mantle makers
Glass blowers
Glass furnace workers
Hairdressers
Herders
Iron workers
Lifeguards
Lithographers
Metal casting inspectors
Miners, open pit
Nurses
Oil field workers
Pipeline workers
Plasma torch operators
Railroad track workers
Ranchers
Road workers
Seamen
Skimmers, glass
Steel mill workers
Stockmen
Stokers
Tobacco irradiators
Vitamin D preparation makers
Welders

* from Key *et al* (1964).

VISIBLE LIGHT

The hazards to man from visible light are few and mostly come from artificial sources, such as lasers. Some of the uses of visible light include quantitative biochemical analysis in the clinical chemistry laboratory, optical and electron microscopy, endoscopy (including the use of coherent fiberoptic bundles for probing in the body), spectroscopy, and holography. In addition, new principles, techniques, and devices, such as light-emitting diodes, optical data processing, integrated optical circuits, phototransistors are now available, and are expanding the use of light in biological applications (7).

INFRARED (IR)

The most prominent direct effects of low wavelength infrared radiations on the skin include the acute skin burn, increased vasodilation of the capillary beds, and an increased pigmentation which can persist for long periods of time. Under conditions of continuous exposure to high intensities of radiations, the erythematous appearance due to vasodilation may become permanent.

Many factors mediate the ability to produce actual skin burn, and it is evident that for this immediate effect, the rate at which the temperature of the skin is permitted to increase is of prime importance. (8) The tolerance limits of the human body for infrared radiations have been determined by several workers.

Lloyd-Smith and Mendelssohn (9) found that an incident intensity of 0.04 cal/cm^2/sec of shortwave infrared could just be tolerated by epigastric and interscapular skin areas of 144 cm^2. Approximately 25% of this energy flux would be reflected, so their result corresponds to a tolerated transmitted intensity of 0.03 cal/cm^2/sec. (9) From the results of Whyte (10) it can be estimated that the maximum incident intensity of long-wave infrared radiation that can be tolerated by a lumbar area, 12 x 12 cm, is also approximately 0.03 cal/cm^2/sec. Here, negligible reflection takes place.

Doses that cause damage

Transmission and absorption factors of the ocular media for the IR spectrum and threshold doses to elicit minimum damage have been determined (8, 11, 12):

1) Dose for corneal damage: 7.6 J/cm^2 - 800-1100 nm; 2.8 J/cm^2 - 1200-1700 nm.

2) Corneal dose to produce damage in the iris: 10.8 J/cm^2 - 800-1100 nm.

3) Corneal dose for production of retinal burns: 1 J/cm^2 (this value determined with a 0.1 sec exposure to 20-40 J/cm^2 causing a 1 mm burn). ▶

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*For a copy of the complete list of references to this article, write *Industrial Medicine & Surgery*, 3625 Woodhead Dr., Northbrook, Ill. 60062.

Occupations potentially associated with IR exposure are shown in Table III.

TABLE III.

Occupations Potentially Associated with Infrared Radiation Exposure*

- Bakers
- Blacksmiths
- Braziers
- Chemists
- Cloth inspectors
- Cooks
- Dryers, lacquer
- Electricians
- Firemen, stationary
- Foundry workers
- Furnace workers
- Gas mantle hardeners
- Glass blowers
- Glass furnace workers
- Heat treaters
- Laser operators
- Iron workers
- Kiln operators
- Motion picture machine operators
- Plasma torch operators
- Skimmers, glass
- Steel mill workers
- Stokers
- Solderers
- Welders

*from Key *et al* (1964)

LASER

The acronym LASER is commonly applied to devices using molecular amplification by stimulated emission of radiation operating with an output wavelength of 200 nm to 2×10^4 nm. It includes masers, optical masers, and lasers and refers to coherent light sources emitting visible, infrared, and/or ultraviolet light. In medicine, lasers are used in various techniques, a main one in surgery, especially eye surgery where the cutting and coagulation capabilities of this energy is utilized. In dentistry, lasers are used to cut hard tooth material.

The primary hazard from laser radiation is exposure of the eye. Radiation levels, if kept below those damaging to the eye, will not harm other tissues and organs of the body. Eye damage can range from mild retinal burns, with little or no loss of visual acuity, to severe lesions with loss of central vision, and total loss of the eye from gross overexposure. In the skin, the laser produces damage in varying degrees, depending upon the type of laser, the duration of exposure, the area of tissue involved. and the incident energy density. (8)

The American National Standards Institute and the U.S. Bureau of Radiological Health are developing laser standards. Because of the complexity of these standards, the official ANSI standard (5) should be consulted.

MICROWAVES

The microwave portion of the electromagnetic spectrum extends from about 300 GHz to 100 MHz. Microwave energy, when propagated, is categorized into two discrete modes known as continuous wave (CW) and pulsed. CW is associated with communication transmitting devices and consumer products. Pulsed microwaves are associated with radar and industrial and medical equipment.

Extensive investigations into microwave bioeffects conclusively show that for frequencies between 1200 MHz and 24,500 MHz, exposure to power density of 100 mW/cm^2 for 1 hour or more could have pathophysiologic manifestations of a thermal nature. At power densities below 100 mW/cm^2, however, evidence of pathologic change is non-existent or equivocal.

Energy transforms to heat

According to the best evidence available, the most important effect of microwave absorption is the conversion of the absorbed energy into heat. Exposure of various species of animals to whole-body microwave radiation at levels of 100 mW/cm^2 or more is characterized by a temperature rise which is a function of the thermal regulatory processes and active adaptation of the animal. The end result is either reversible or irreversible change depending on the conditions of the irradiation and the physiologic state of the animal. (3)

Irradiance levels of 10,000 MHz and 3000 MHz microwaves as well as infrared stimuli producing a threshold sensation of warmth are summarized in Table IV. These data indicate that when a 40 cm^2 area of the face is exposed to microwaves, thermal sensation can be elicited within 1 second at power densities of 21 mW/cm^2 for 10,000 MHz and 58.6 mW/cm^2 for 3000 MHz. Within 4 seconds, the threshold is lowered by approximately 50%, i.e. 12.5 mW/cm^2 (10,000 MHz) and 33.5 mW/cm^2 (3000 MHz) (13, 14). On this basis, if the entire face were to be exposed, the threshold for thermal sensation to 10,000 MHz would be 4-6 mW/cm^2 within 5 seconds or approximately 10 mW/cm^2 for a 0.5 second exposure. (15)

Threshold for pain reaction to 3000 MHz exposure of a 9.5 cm^2 area of the forearm ranges from 830 mW/cm^2 for exposures longer than 3 minutes to 5.6 W/cm^2 for a 20 second exposure period. If a

TABLE IV.

Stimulus Intensity and Temperature Increase to Produce Threshold Warmth Sensation*

Exposure Time (sec)	3000 MHz	10,000 MHz		Far Infrared	
	Power Density (mW/cm^2)	Power Density (mW/cm^2)	Increase in Skin Temp. (°C)	Power Density (mW/cm^2)	Increase in Skin Temp. (°C)
1	58.6	21.0	.025	4.2-8.4	.035
2	46.0	16.7	.040	4.2	.025
4	33.5	12.6	.060	4.2	...

* 37 cm^{2}forehead surface area—data from Hendler, E. *et al* (1963, 1968)

larger area (53 cm^2) is exposed, the pain threshold for a 3-minute exposure is 560 mW/cm^2. (16) These data and other information on microwave sensation suggest that cutaneous perception of microwaves may provide a protection factor with sufficient margin of safety constituting a warning mechanism to prevent exposure to microwaves at levels that could be injurious. (3)

Rapid rise in temperature

In areas of the body in which relatively little blood circulates, the temperature may rise more rapidly than in vascular parts of the body, since mechanisms for the interchange of heat are insufficient. Tissue damage is more likely to occur in those areas where proportionately a greater rise in temperature can occur. Thus, the lens of the eye may be more susceptible to thermal damage, since this structure does not possess an adequate vascular system for the efficient exchange of heat. Therefore, at power density (>100 mW/cm^2) duration (1 hour) exposures sufficient to produce excessive heat generation, opacities may develop in the lens, with the end result being cataract production. (3) Some occupations in which microwave energy is used are shown in Table V.

Thermal considerations and the rather extensive body of experimental data available from the Tri-Service sponsored studies. (17) have been reviewed in Subcommittee 4 of the American National Standards Institute (ANSI) Committee C95.1, which in 1966 recommended 10 mW/cm^2 as the standard. (4) In June 1973, this standard was reaffirmed by the American National Standards Institute.

TABLE V.
Occupations Potentially
Associated with
Microwave Exposure*

Air crewmen
Electronic engineers
Furniture-veneering operators
Microwave-development workers
Microwave-diathermy operators
Drug sterilizers

Microwave testers
Missile launchers
Radar mechanics
Radar operators
Microwave-oven maintenance workers
Physicists
Food sterilizers

*from Key *et al* (1964).

RADIOFREQUENCY (RF)

Behling (18) and Kall (19) have reviewed the literature on the biologic effects of radio- and low-frequency (<30 MHz) electromagnetic radiation. Below 30 MHz, no resonant heating occurs and the RF energy completely penetrates the body. Radio- and low-frequency radiation emitters usually include transmitting devices. Broadcast stations, boosters, and radio transmitters make the greatest contribution to the observed ambient radiation levels in the radio-frequency range.

There is no evidence of hazard to man from radio-frequency energy under normal conditions of operation and exposure. Although broadcast stations are regulated by the Federal Communications Commission, this is mainly to prevent mutual interference of broadcast activities.

Radiation in tall buildings

According to Harris (20), the specifications for UHF TV stations (channels 14 to 83) could lead to ground level radiation in excess of 2 mW/cm^2. Further, it is possible that radiation levels in tall buildings in the vicinity of buildings supporting transmitter towers may be considerably higher than 2 mW/cm^2.

The currently accepted U.S. exposure standard for microwaves, which is 10 mW/cm^2 averaged over any possible 0.1-hour period (4), includes the frequency range of 10 MHz to 100,000 MHz. Studies by Bollinger (21) which revealed no effects after 1-hour exposures to 100-200 mW/cm^2 of 10.5, 19.3 and 26.6 MHz may be indicative that the safety standard for low-frequency (<100 MHz) radio-frequency radiation could be raised above 10 mW/cm^2.

On the basis of their analysis and experimental work, Rogers and King (22) suggest that under plane-wave (far-field) conditions, the body could endure an RF radiation power density greater than 10 mW/cm^2 ($E_i \approx 200$ V/m) for frequencies in the h.f. band and conclude that an electric-field strength of 1000 V/m is considered to be the safe limit for continuous daily exposure to radio-frequency radiation in the range below 30 MHz.

When standards fail

Schwan (23) in his most recent review of microwave radiation and standards criteria points out that there are circumstances in which standards based on flux levels fail. This happens in the presence of complex field patterns, i.e., in the near field of antennas or in the presence of several fields as may be generated by several transmitters or by reflecting surfaces.

In such cases, the concept of flux becomes meaningless. He suggests that under these circumstances a tolerance current density in tissue of 3mA/cm^2 may well serve as a better guide for work-related exposure in complex fields. This current density corresponds for simple fields to a flux of 10 mW/cm^2 between 100 and 1000 MHz. Therefore, protection guide numbers may be as follows:

1. 3 mA/cm^2 for frequencies above 10 MHz
2. 1 mA/cm^2 for frequencies from 10 KHz to 10 MHz
3. 0.3 mA/cm^2 for frequencies below 10 KHz IMS

This article is based on research work performed under Contract No. FDA 73-30 with the Food and Drug Administration and the U.S. Atomic Energy Commission. Dr. Michaelson presented a paper on this subject at the 8th Inter-American Conference on Toxicology and Occupational Medicine, Miami, Florida, July 8-11, 1973. For reprints, contact Dr. Michaelson at the School of Medicine and Dentistry, University of Rochester, N.Y. 14642.

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