CONSIDERATIONS AND CRITERIA FOR A RECOMMENDED STANDARD FOR OCCUPATIONAL EXPOSURE TO RADIOFREQUENCY AND MICROWAVE FIELDS

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In May 1978, NIOSH initiated the development of a criteria document to include a recommended occupational exposure standard for worker protection from radiofrequency (RF) and microwave fields. The document is scheduled for completion by August 1979. Preparation of the criteria and recommendations has involved: NIOSH research and field studies prior to initiation of the formal document effort; an extensive review of world bioeffects literature on the subject; communication with industry, organized labor, trade association, professional societies, and academia; plant visits; and extensive internal and external review by individuals selected for their expertise in particular aspects dealt with in the document.

The recommendations are based upon a critical evaluation of the biological effects and epidemiological data (or, at times, lack thereof) and consideration of available instrumentation, engineering controls, work practices, and medical monitoring. In addition, an attempt was made to determine the potential extent of exposure. Over 300 letters were sent to manufacturers of RF/microwave equipment, users and potential users of RF and microwave fields (including some government-operated and -sponsored research laboratories), trade associations, and organized labor. NIOSH received approximately 70 responses to these letters, and participated in 8 plant visits arising therefrom. A summary of the observations of these plant visits is the subject of another presentation at this symposium. The criteria are proposed to apply to all workers exposed or potentially exposed to RF/microwave fields of frequencies between 500 kilohertz and 300 gigahertz.

(a) Permissible Exposure Limit

There is a lack of agreement in the literature on the production of certain biologic effects by RF and microwave energy. Even though results are often contradictory when comparing some of the published studies, there still exists a rather large body of reports that document the appearance of certain effects after exposure of humans and animals to RF and microwave fields. It is generally agreed that RF/microwave exposure at or above a far-field power density of 10 mW/sq cm* can cause a net rise in the body temperature of man, and therefore should be avoided. In many cases, however, literature reports have described biologic changes at levels below those necessary for the production of a net rise in body temperature. A good deal of controversy over these so-called nonthermal effects exists. Nonetheless, documentation of them is sufficient to cause concern, and a cautious approach appears warranged in establishing exposure limits to RF and microwave fields pending further research.

The absorption of electromagnetic energy in the RF and microwave frequency range has been shown to depend strongly on the configuration and shape, orientation, and electrical properties of the object being irradiated. In humans, maximum whole-body absorption of RF/microwave energy occurs in the 70- to

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*Or the equivalent electric and magnetic field strengths of approximately 200 V/m and 0.5 A/m, respectively.

100-MHz range with a peak at about 80 MHz. Local absorption in the legs and neck also occurs in this frequency range, and partial-body resonant frequencies occur for the arm at 150 MHz and head at 350 MHz. Human absorption below approximately 30 MHz and above about 500 MHz is considerably less than that in the 30-500 MHz range. In view of the above considerations, the recommended standard is frequency dependent.

The frequency range of greatest concern is that in which maximum human absorption occurs. This region includes frequencies between 10 MHz and 500 MHz. Studies of animals exposed in this frequency range have shown the production of certain biologic effects. Experiments involving long-term exposure of rats and rabbits to 50 MHz at 0.5-6 V/m have reportedly resulted in increased urinary excretion of 17-ketosteroids; alterations in EEG patterns and conditioned reflex behavior; and decreased leukocyte count, blood cholinesterase, and phagocytic activity. Long-term exposure of rats to 69.8 MHz at 5-48 V/m reportedly resulted in decreased thyroid gland weight, increased adrenal gland weight, and increased pituitary gland weight, while exposure at 150 V/m resulted in temporary changes in conditioned reflex behavior. Experiments performed at 14.88 MHz have reportedly shown decreased thyroid and adrenal weights in rats multiply exposed at 70 V/m, and an increase in phagocytic and bactericidal activity after long-term exposure of rats at 100 V/m.

Whether these effects in animals constitute occupational hazards (to man) is not clear. However, the above reports do suggest that deviations in normal biologic variables can result from exposure to RF and microwave energy at frequencies where maximum human absorption occurs. It should be emphasized that humans would absorb at a higher rate than would laboratory animals in the frequency range (14-70 MHz) used in the above experiments. Therefore, it is possible that similar effects could be seen in humans at even lower doses than those reported for animals.

In the lower frequency range (500 kHz-10 MHz), biologic effects data are not presently available. However, model data indicate that human whole-body absorption drops off rapidly below 10 MHz. Further research is needed in this frequency range. Many effects have also been reported after irradiation at power densities above 10 mW/sq cm. In addition, there are some reports of similar adverse effects in humans with regard to ocular changes, changes in neuroendocrine functions, behavioral changes, cardiovascular effects, and changes in blood chemistry, immunologic function, and spermatogenesis.

Numerous animal studies have described the production of certain biologic effects at frequencies above 500 MHz. Most of these experiments have involved frequencies in the range of 1-5 GHz (a region of resonant absorption for small animals), but in a few experiments, animals have been irradiated at frequencies of up to 60 GHz. The reported effects and power densities have included ocular changes at 5-10 mW/sq cm, alterations in certain neuroendocrine functions at 0.01-15 mW/sq cm, microscopic changes in CNS tissue at 2-10 mW/sq cm, alterations in neurotransmitter levels at 10 mW/sq cm, effects on the peripheral nervous system at 1-10 mW/sq cm, changes in permeability of the blood-brain barrier at 0.03-10 mW/sq cm, alterations in EEG at 0.02-5 mW/sq cm, changes in various behavioral patterns at 0.1-15 mW/sq cm, changes in cardiac rate at 3-12 mW/sq cm, alterations in various blood and bone marrow parameters at 0.05-10 mW/sq cm, changes in the immunologic system at 0.5-10 mW/sq cm, teratogenic and embryotoxic effects at 10 mW/sq cm, and reproductive effects at 10 mW/sq cm.

(b) Monitoring

A variety of equipment is available for measuring field strengths (or power density) in the vicinity of RF/microwave-emitting devices. Monitors are currently in a state of development, and neither an instrument nor a measurement technique has been accepted and validated for use in general occupational situations. The Bureau of Radiological Health (BRH) has specified electronic and physical characteristics that must be met by monitors to be used in testing for compliance to the present microwave oven emission standard; however, such special-purpose probes have limited applicability in most industrial, medical, and communications facilities.

A broadband probe exhibiting a linear, isotropic response over a wide dynamic range (i.e., able to read field strengths over one or two orders of magnitude or power densities over several orders of magnitude) is desired. The probe should be capable of high resolution of the spatial distribution of the field, and should not perturb the field during measurement. Detector elements using diodes, thermistors, or thermocouples are preferred because of their small size, low sensitivity to burnout and ambient temperature, and linear response to incident fields, relative to liquid crystal, gas pressure, gas discharge, or pyroelectric devices.

Several portable, as well as fixed, monitors that are commercially available provide values for power density, despite the fact that electric or magnetic field strength (actually the mean squared value of the field strength) is the real quantity measured. Monitors giving field strength values are essential for measurements of possible occupational exposures under near-field conditions where the electric and magnetic field strengths and the power density are not related by simple mathematical expressions. Three additional design features that deserve consideration are an alarm that will sound at some preset intensity level, and capabilities for recall of the highest power density or field strength level encountered during a scan of the exposure area, and for integrating the total power density or field strength over any time period.

Standardization of measurement procedures and calibration techniques has begun, but at present the techniques appear to be tailored to each specific measurement situation. Present calibration methods relying on standard free-space fields or waveguides to produce known uniform fields require relatively sophisticated equipment not available to most industries. A secondary, transferable standard probe to which all monitors are calibrated represents a more feasible method.

(c) Medical Surveillance and Recordkeeping

Health surveillance can be as important as continual technical surveillance (i.e., monitoring of field strengths) in controlling exposure. Although monitoring of the electromagnetic field can determine that initial or further exposure to the field should be prohibited, health surveillance can ideally only limit subsequent exposure once a radiation-induced effect has been noted. A consideration of the biologic effects of irradiation with RF and microwave energies indicates that some of the effects might serve as clinically detectable symptoms of exposure. Whether these are specific to RF/microwave irradiation has yet to be determined. For example, that the observed effects are indicative of nothing more than a general physiologic response to thermal stress has been hypothesized by some investigators. Thus, a battery of valid tests for diagnosis of exposure of man to RF/microwave fields is not presently available.

Some of the specific tests suggested for medical surveillance entail examinations of the hematologic, immunologic, neuroendocrine, cardiovascular, and reproductive (males only) systems; neurologic tests and behavioral observations; and ophthalmologic examinations. Examples of the indices measured are differential blood count (red and white cells), adrenaline excretion, heart rate, sperm motility, latency and amplitude of EEG, motor activity and emotional state, and eye opacities. A cause-effect relationship between the level of exposure and the magnitude of the physiologic response has not been determined. Any observations made during an examination must be considered as merely indicating a possible exposure to RF and microwave energies above the recommended limit.

The questionable utility of health surveillance suggests that medical examinations of workers exposed at low field strengths should not be necessary. However, since information on the relative deleterious or adverse nature of RF and microwave radiation is lacking, a program of continual medical surveillance of all occupationally exposed personnel may provide needed data on the harmful effects to humans and on which a future standard could be partially based.

(d) Personal Protective Equipment and Clothing

Since the utility of such equipment has been questioned, and since under certain situations a suit could actually magnify the field density incident on certain parts of the body, no recommendations concerning protective suits and goggles are possible.

(e) Informing Employees of Hazards

Education and orientation programs are probably the most effective ways of minimizing unnecessary occupational exposure, and should include discussions of the possible dangers and medical signs of overexposure to RF/microwave energy. Since health surveillance, to a limited extent, and continuous monitoring of the RF field appear to represent efficient ways of controlling exposure, employees should be made aware of the biologic effects of RF/microwave energy, and should also be familiar with the techniques used and values measured during routine monitoring of the RF/microwave field. The results of health examinations and radiation monitoring must be made known to the employee as soon as possible after their completion. The use of RF/microwave energy-emitting devices only by trained and authorized persons must be stressed. The function and efficiency of engineering controls such as shielding, interlocks, dummy loads, and wavetraps should be mentioned during the training period.

It is recommended that knowledgeable supervisory staff be responsible for disseminating all information during an employee's orientation and training, and that booklets or manuals not be relied on. In this way, any questions an employee may have can be answered immediately and on a personal basis. The goal of such a program will be to ensure understanding of the problems and the solutions. Any educational program instituted ought to cover, in a general manner, the hazards and the philosophy and techniques of avoiding overexposure to RF/microwave fields.

(f) Work Practices

Work practices should focus on limiting the time spent by an employee within an electromagnetic field generated at RF/microwave frequencies. Eliminating exposure should be the goal of this approach. For example, switching equipment off before maintenance or "tuning" is performed is preferable to servicing equipment while it is in operation. Informing employees as to where RF/microwave fields can be expected to occur, either directly by posting signs indicating restricted or hazardous areas, or indirectly through an educational program that describes the probable field distribution around the radiation-emitting device, is an efficient precautionary measure. Plant management should be made aware that it has the responsibility for controlling the exposure of its work force to RF/microwave fields.

(g) Engineering Controls

Enclosure of RF/microwave-emitting devices (sources, transmission lines, and antennas where possible) is effective in many situations in containing RF and microwave fields. Properly grounded and installed shields made of rigid metal sheets, flexible metallized fabrics or wire mesh, and metal-coated glass used in conjunction with absorbent coatings and reflective paints will limit exposure of operators from primary, as well as secondary, sources.

Interlocks that prevent the source from being turned on except when a device is completely closed are useful for oven-type irradiation chambers. Interlocking bronze and spring-steel fingers and "choke" seals (wavetraps) can prevent leakage of RF/microwave energy from the edges of chamber doors. Conveyorized systems should contain dummy loads, wavetraps, or grounded curtains to redirect escaping RF/microwave fields back into the chamber or away from the operator. Diathermy applicators and electrosurgery devices should be equipped with shields or focusing elements to limit the release of RF/microwave energy to the desired site on the patient, and not toward the operator. Broadcast and radar antennas should, wherever possible, have shielding on their underside to intercept signals inadvertently directed toward the ground.

Since a wide range of materials is available, interposition of shielding between a device and its operator, as well as other employees in the vicinity, is feasible for a variety of industrial applications. The placement of shields can be determined by mapping the field strength distribution around the equipment with an RF/microwave energy monitor.

(h) Monitoring and Recordkeeping Requirements

It is recommended that a systematic program to measure electric and magnetic field strengths around RF-emitting equipment installed at the workplace be instituted. These procedures will yield information on safe (in relation to the recommended limit) areas, areas in which shielding must be added, and areas to which access, or in which the time spent, is limited.

In addition, monitors should be available for continuous surveillance of the electromagnetic fields. A program of periodic measurements with portable, sensitive isotropic probes should be instituted. The schedule of monitoring should take into account the maximum exposure level that is expected or conceivably can occur.