MICROWAVE RADIATION

Art Dula, Esq.*

ABSTRACT

Theory supporting present microwave exposure standards is reviewed in light of their history, and a comparison is made with the standards adopted by several foreign countries.

The Radiation Control for Health and Safety Act of 1968 is analyzed. Regulations promulgated under its authority are traced to the latest recodification of law. The statutes and regulations are discussed procedurally and substantively. Special attention is paid to the regulation of microwave ovens.

I.
LEGAL REGULATION OF MICROWAVE RADIATION

A. History of Microwave Exposure Standards

1. *Early Use of Microwaves*

Radar's development for military use during World War II introduced a new range of electromagnetic radiation, microwaves, into man's environment. Earlier, technology limited the production of electromagnetic radiation to long wavelength radio waves.

Initial applications of microwave radiation were limited to military radar systems, but use of radar is now commonplace. The unique ability of some frequencies of microwave radiation to penetrate deeply into solid material, producing internal heating, results in a wide variety of uses for this energy. Applications include diathermy, drying and freeze-

*Art Dula is a practicing attorney in Houston, Texas, and a member of the Council of the Section of Science & Technology.

drying food, sealing, cooking, reheating, moisture levelling, and sterilization. Future applications include use of microwave ionized gases in chemical reactions, space propulsion, controlled nuclear fusion, and "wireless" power transmission.

2. *Early U.S. Regulations*

Microwave radiation protection guides were first proposed by Schwan in 1953 based on simple physiological considerations. Schwan suggested a radiation exposure level of 10 mW/cm².[2] This standard was adopted by a Triservice Committee in 1957 and rapidly gained widespread acceptance by both government and private industry.[2] The deliberations of this Committee and an extensive body of experimental data were reviewed by Sub-Committee IV of the American National Standards Institute (ANSI) Committee C95.1, which, in 1966, recommended 10 mW/cm² as an acceptable standard.[3]

This "safe" limit of 10 mW/cm² resulted from two lines of reasoning. First, it had been experimentally and theoretically determined that continuous whole body exposure of a human to this power level resulted in a maximum equilibrium temperature rise of one degree centigrade. The Committee felt this level was tolerable on a long-term basis without risk of irreversible damage.[4] Second, experimental investigations on animals indicated irreversible tissue damage occurred at power densities of about 100 mW/cm². A safety factor of 10 resulted in the level of 10 mW/cm². It is generally agreed that thermal effects predominate at levels greater than 10 mW/cm², and that below this power density level nonthermal effects predominate.

3. *Early Russian Research and Standards*

In the early 1950s Russian experimenters seriously investigated the effects of ultrahigh frequency electromagnetic fields on the nervous systems of animals and men.[5] At this time, U.S. studies were limited to detecting thermal effects in tissue. Thermal effects were not detectable at levels below those of the Triservice standards.

Russian studies of microwave workers resulted in a number of important phenomena being related to microwave radiation. Their studies indicate that the central nervous system is particularly sensitive to microwave radiation. Reported effects of chronic occupational exposure to very low power microwave radiation in humans include: disruption of the endocrine-humeral process, hypertension, intensification of thyroid activity, an exhausting influence on the central nervous system, a decrease in the sensitivity of smell, and an increase in the histamine content of the blood. There were also many subjective complaints from the

525 workers examined in one study. These include: increased fatigue, periodic or constant headache, extreme irritability, and sleepiness during work.

In contrast to these findings, researchers in the United States who attempted to duplicate Soviet results, found no acute, transient, or cumulative physiological or psychological changes that could be attributed solely to microwave exposure.[6,7]

Russia subsequently adopted standards for exposure to microwave radiation 1,000 times lower than equivalent United States standards. Thus, as of 1977, the United States and the Soviet Union have microwave safety standards that differ by two to three orders of magnitude.

4. *Later U.S. Standards*

a. *USASI.* On the basis of thermal damage criteria, the United States American Standards Institute (USASI) in 1966 adopted 10 mW/cm² for an .1 hour period as the maximum permissible microwave dose.[8] Present microwave exposure standards accepted by the U.S. Military and many industrial microwave users are generally similar to USASI standards.

b. *Bell Telephone.* Bell Telephone Laboratories, because of their extensive experience with microwaves, has adopted a more conservative limit.[9] Under present Bell standards: "(1) Power levels in excess of 10 mW/cm² are potentially hazardous, and personnel must not be permitted to enter areas where major parts of their bodies may be exposed to such levels. (2) Power levels between 1 and 10 mW/cm² are to be considered safe only for incidental, occasional, or casual exposure, but are not permissible for indefinitely prolonged exposures."

As of 1968, nine states out of thirty-eight reported microwave safety criteria were utilized to make recommendations for control of possible health hazards from radiation. Seven of these states used a standard of 10 mW/cm² and three used the Bell Telephone Laboratories standard. As of 1968, therefore, the generally accepted microwave exposure standard was 10 mW/cm² with some acceptance of a slightly lower standard.

5. *Foreign Microwave Safety Standards*

a. *Russia.* The Soviet Union's vast amount of research and experience with microwaves has been outlined above. Radiation between 300 and 300,000 MHz is considered to be "microwave." The following standards are presently in force in the Soviet Union for frequencies greater than 300 MHz:

.01 mW/cm² for a working day

.1 mW/cm² for 2 hours a day

1 mW/cm² for 15 minutes a day

The USSR was the first nation to propose exposure standards for low frequency electromagnetic radiation. Present standards are:

Medium Wave (100 KHz—3 MHz)	—20 volts/meter
Short Wave (3 MHz—30 MHz)	5 volts/meter
Ultra Short Wave (30 MHz—300MHz)	—5 volts/meter

Medical examinations are required in the USSR for workers exposed to electromagnetic radiation. Preventive measures in design engineering are also stressed. Naturally, since the USSR is a totalitarian state, these standards are law.[10]

b. *England.* In the United Kingdom recommendations on microwave radiation cover 30 to 30,000 MH². Continuous daily exposure is limited to 10 mW/cm² with no reference to a time weighted average. If it can be proven that no radiation intensity of greater than 1 mW/cm² can be reached anywhere where anyone would normally and reasonably have access, then measurements do not have to be made. In the event of an over-exposure exceeding 10 mW/cm², a medical examination is required, along with measurements of the intensity of the radiation to which the individual was exposed.[11]

c. *France.* French military guidelines have been set at 10 mW/cm² for exposures of one hour or longer. A *de facto* 55 mW/cm² limit is recognized for periods of less than one hour. For public areas a limit of 1 mW/cm² is considered "desirable."[12]

d. *Poland.* Poland has conducted much of the eastern European research on the health effects of microwave radiation. On the basis of this research the Council of Ministers in 1961 officially adopted an order containing many rules for work with microwaves. The principal articles state:

> The fol'owing maxium allowable mean values of the power intensity of the electromagnetic field of microwaves are laid down for areas where people are present:
>
> 1. Intensity .01 mW/cm²—no limit
> 2. Intensity .01-.1 mW/cm²—cumulative exposure time not to exceed 2 hours out of 24.
> 3. Intensity .1-1 mW/cm²—cumulative exposure time not to exceed 20 minutes in 24 hours.
>
> No person shall remain in an electromagnetic field of an intensity exceeding 1 mW/cm² unless in cases of emergency and on the condition that special protective measures, as decided for each case by the person in charge of the undertaking, are taken.

Poland also has medical standards that must be met by young people, pregnant women, and other people suffering from listed diseases prior to work with microwave radiation. Preplacement medical examinations are also required.[13,14]

e. *West Germany.* The West German Association for Radar and Navigation has published a guide that is considered authoritative in the Federal Republic. It sets the critical limit of microwave radiation intensity at 10 mW/cm² for human exposure. No allowance is made for time of exposure.[15]

f. *Czechoslovakia.* Czechoslovakia passed a very complex set of microwave radiation guidelines in 1968. The standards it establishes are a multiple of radiation energy flow per unit area and time. Translated into Western terms they are roughly:

1. Maximum daily dose—8 hours at .01 mW/cm² for workers with microwave units in industry (pulsed radiation).
2. Maximum daily dose—24 hours at .001 mW/cm² for the general population and all other workers (pulsed radiation.)[16]

Thus Czechoslovakia presently has the highest standards governing exposure of the general population to microwave radiation of any nation in the world. The standard for continuous radiation is two-and-one-half times that of pulsed radiation.

g. *An East/West Dichotomy.* A dichotomy is apparent from these differing national standards. The Western nations within the U.S. sphere of influence generally follow the U.S. standard (10 mW/cm²) without a time limit. These nations also tend not to report research into nonthermal effects of microwave radiation. Nations within the Soviet orbit, conversely, actively research nonthermal effects and have very strict (.01 mW/cm²) time dependent microwave safety standards. The United States has begun to adopt stricter standards in some areas, notably the use of microwave ovens, but most industrial users of microwaves are still not limited by any legal standard.

B. Dimensions of Potential Microwave Problems

1. *Extent of Exposure—Microwaves*

As of 1970, over 100,000 microwave ovens were in commercial and private use. Total sales of microwave ovens is presently over 100,000 per year. Microwave ovens constitute at least 25% of all oven sales, providing a total of more than 1,800,000 units by 1976.[17]

Significantly, most microwave ovens are owned by commercial, industrial, and educational establishments. These institutions use microwave ovens in snack bars, cafeterias, and restaurants. Such use exposes a relatively larger segment of the population to any possible radiation

emitted by ovens than would be the case if most of these ovens were in private homes. Most ovens in commercial use are serviced by private repair companies, food service contractors, or vending machine dealers. Such non-regulated installation and service strongly suggests that emission control of radiation from microwave ovens will degenerate over time. Empirical study has established that such leakage can be normally expected to increase as an oven grows older. These same studies show that the repair of such ovens usually proceeds only to the point of strictly electrical and mechanical changes needed to "make it work" with no thought to minimizing microwave radiation. Indeed, in several instances leakage after repairs was found to be greater than before repairs were made. Finally, repairman who service ovens are frequently occupationally exposed to microwave radiation. Under "worst case" circumstances, such exposure is quite severe. During repair the purpose of an oven's shielding and safety interlocks can be defeated and expose unknowing personnel to cooking level radiation normally found only inside the oven during the regular operation.[18]

2. *Extent of Exposure—Radio Waves*

Radio waves, the lowest energy electromagnetic radiation, has been least studied from an environmental and biological point of view. Most powerful sources of radio frequency radiation are coextensive with large population centers in cities. Radio and television stations radiate millions of watts of radio frequency energy into urban environments each day. Often their transmitting antennae are set on office buildings or are within a few hundred feet of homes and apartments. Thus any effects produced by exposure to this radiation could be of immense importance to public health and safety.

3. *Recent Research Results in Radio Waves*

Until very recently and especially in the United States, radio frequency radiation was not considered a possible hazard to man.[19] People have lived in the presence of such fields for decades without observing any obvious harmful effects. This attitude has been reinforced by studies conducted on animals and by the high radio frequency power densities required to generate thermal effects.[20] Nonthermal effects such as "pearl chain" formation in human blood and certain enzymatic effects and chromosomal aberrations have been unknown, disputed or ignored.[21]

Recent research indicates both microwave and radio frequency radiation interact directly with man's central nervous system to cause behavioral changes.[22] These findings confirm long-established Russian research indicating radio frequency fields cause long-term behavior

changes in human populations.[23] Reported effects include long-term hyperactivity, increased emotionality, slower learning, and increased general irritability.[24] The size of the urban population exposed to such radiation requires that the problem of finding behavioral effects becomes one of statistical analysis. The lack of a control group that has not been exposed to the radiation creates difficulties. The possibility of errors in rural-urban cultural comparisons may invalidate any statistical study. Finally, these effects seem to be more psychological than biochemical and may be studied better by urban sociologists than public health officials.

4. *The Interdisciplinary Problems of Regulating Radio and Microwaves*

The regulation of microwave and radio frequency radiation presents a problem in communication. Equipment generating the radiation is in the province of electrical engineering. Propogation of the radiation and its interaction with living tissue is a concern of radiation physicists. Effects on living systems are studied by biologists and epidemiologists. Low power effects on the central nervous system require the attention of psychologists and sociologists. Finally, regulation involves lawyers.

Admittedly, every technical difficulty encountered in today's complex technical world is multifaceted, but the environmental effects of electromagnetic radiation present more problems than most. Several disciplines needed to understand the problem, for example, electrical engineering psychology and biophysics, are almost mutually exclusive. That is, a specialist working in one area not only does not understand the other, but is unaware that his problem even interacts with the other field. Also, many of these groups have professional interests at stake. For example, most electrical engineers are employed by industries producing equipment that emit electromagnetic radiation. Naturally papers published in their professional journals play down the importance of nonthermal effects. Psychologists, conversely, find such nonthermal effects to be of utmost importance, but they fail to understand the technical difficulties involved in reducing the hazards. Lawyers do not understand, except in a most general way, any technical arguments. Yet this group will be called on to draft, or at least decide between, standards to be adopted for protection of public health and safety.

5. *Recent Developments and the Future*

a. *Thermal Damage.* On November 9, 1972, a Korean War Navy veteran was granted a service-connected disability award for radar-related bilateral cataracts by the Board of Veterans Appeals. This was the first radar-related disability award made in the United States

and it was made 10-15 years after the exposure that caused the injury. Similar thermal, or high power, effects of microwaves are now well accepted.

b. *Causes of Nonthermal Effects.* Recent research suggests mechanisms by which nonthermal, or low power, microwave radiation can influence the human central nervous system. One speculative mechanism is that the electromagnetic field may alter membrane permeability in nerve cells.[25] Another postulates the shifting of protein molecules in cell membrances, i.e., as in the mechanisms of sight. A third suggests that microwaves may cause localized cell heating not detectable as gross thermal effects. The important point made by these studies is that recent American research results with animals confirm the existence of the behavioral effects Russian researchers have long reported in humans.[26]

Functionally, some portions of the human body, especially the head, act to focus microwave radiation and create "hot spots" within the skull.[27] This effect varies with radiation frequency and may be unimportant at low frequencies, but dangerous at microwave frequencies.[28,29] It also appears that the magnetic component of the electromagnetic field may interact with the central nervous system, especially at low frequencies.[30] Whatever the mechanism, microwave radiation can have a variety of physical and psychological effects on the human organism.

The little experimental work done on man indicates that these effects include possible alterations of the sensitivity of various sense organs, particularly auditory[31] and olfactory threshold changes.[32] There have been reported cases concerning the role of microwave radiation in a variety of disorders of the brain and nervous system, such as a causative role in severe neurotic syndrome [33] and astrocytoma of the brain.[34]

c. *Reported Nonthermal Symptoms.* Symptoms reported in two United States studies included "typical frontal headache," intraocular pain, fatigue, nervousness, and an awareness of buzzing vibrations or pulsations.[35] Unfortunately, published studies virtually ceased in the United States after the mid-1950s and the remainder of the considerable research that continued to be reported is found only in the literature of the USSR and other eastern European countries. Symptoms and signs reported in some of these studies include headache, increased fatigability, increased irritability, dizziness, loss of appetite, sleepiness, sweating, difficulties in concentration or memory, depression, emotional instability, dermographism, thyroid gland enlargement and tremor of extended fingers.[36] All of these are considered to result from typical microwave induced functional disturbances of the central nervous system. Associated with these clinical symptoms are electroencephalographic (EEG) changes, decrease in thealpha wave index and increases in theta and delta wave percentages.[37] Another frequently described manifestation of

microwave irradiation is cardiovascular changes and is attributed to action by microwaves on the autonomic nervous system. A third group of findings, called the diencephalic syndrome, is more serious, but less frequent than the others. It includes hallucinations, insomnia, and inhibition of visceral functions. Repeatedly, the frequency and severity of clinical signs are reported to increase with long-term exposure. Finally, it has been reported that exposure to microwave radiation in early pregnancy can cause abortion.[38] This growing body of literature, from many countries, describing a wide variety of functional changes and clinical effects leading to consideration of "radio wave sickness" as a possible nosologic entity, cannot be ignored.[39] As the use and power of microwave radiation increases, the stage is set for the appearance of other effects previously undetected, possibly because of their infrequency, lack of distinctiveness or mild character.

d. *Leakage in Microwave Ovens.* Increasing use and power pose no threat to human health and safety if microwave equipment does not emit harmful amounts of radiation into the environment. The most common source of microwave irradiation is the microwave oven. Therefore it is desirable to determine if microwave ovens "leak" more microwave radiation than is safe. Safety, as of 1977, can be defined as the maximum legally allowable level, which is 5 mW/cm² at a distance of 5 cm from the oven's door.

One study of leakage from microwave ovens was made by the U.S. Army in 1967. This study reported that 80% of 30 ovens tested were found to be leaking more than 10 mW/cm². A later Army study indicated that 64% of 14 ovens leaked more than 10 mW/cm². Of 42 ovens tested in Florida, 36 leaked in excess of the legal standard. In Utah 29% of 93 ovens tested were found to be leaking in excess of 10 mW/cm².[40] More recently, a 1970 study of 187 ovens in commercial service in Washington, D.C., found that only 2.9% of the ovens were leaking in excess of the legal standard during closed operation.[41] However, the distance between the human body and the oven is critical to the amount of radiation received by the body. Normally, the operator is closest to the oven when it is opened and closed. This same Washington, D.C., study indicated that over 60% of the 187 ovens tested leaked more than 10 mW/cm² while their doors were being opened. Thus it appears that a majority of microwave ovens operate so as to emit more than the legally permitted maximum amount of microwave radiation during the critical time when the operator is nearest the oven.

e. *Future Uses of Microwaves.* Microwave ovens are the most visible source of microwave radiation, but they can be made safe because the microwave radiation can be confined while the oven operates. Of greater potential danger are the uses of high-powered microwaves where the radiation must be unconfined to perform its function. Pres-

ently this is the case only for microwave communication beams. In the future, however, the largest source of unshielded microwave power will be the microwave power beams used for broadcast power transmission. This type of high-energy microwave beam is the only practical way to move large amounts of electric power from space to earth. In the future, as we turn to solar energy, large solar power stations will be constructed in geostationary orbit. Power collected in space will be transmitted to earth as a beam of microwave radiation, which will be converted on earth to electric power. The resultant energy will have been generated free of conventional air or water pollution. In this example, as in all the uses of microwave energy, a choice must be made between the benefit gained and the effect sustained. This choice must be as informed as possible to maximize the utility of the technology.

II.
THE RADIATION CONTROL FOR HEALTH AND SAFETY ACT OF 1968

Passage of Public Law 90-602, the Radiation Control for Health and Safety Act of 1968, began a new era in the relationship between federal health authorities and the electronics products industry. The Act establishes the federal government's authority to issue radiation safety performance standards for commercial electronic products and to correct defects relating to radiation safety.

A. Legislative History

The Act became effective after 14 months of hearings. Representatives from the government and the public convinced Congress, over arguments presented by the electronics products industry, that both ionizing and non-ionizing radiation emitted from electronic products presented a hazard to the public health. To guard the public against this danger, the Act provides for establishment of an "electronic product radiation control program" that is to include "development and administration of performance standards to control the emission of electronic product radiation."

B. Scope of the Act

The Act specifically deals with three main classes of electronic product radiation: (1) ionizing electromagnetic radiation; (2) non-ionizing electromagnetic radiation; and (3) sound waves of all types (infersonic, sonic and ultrasonic).

These forms of radiation are produced by "electronic products,"

which the Act defines as "any manufactured or assembled product that does or could emit" any of the above radiation. The Act directs that studies be conducted in a variety of areas concerned with health hazards arising from electronic product radiation and that an annual report be made to the Congress containing suggestions for legislation. The Act specifies procedures governing the development, promulgation and administration of standards for electronic products. It details methods for testing and rejecting noncomplying imports, specifies how records are to be kept and what inspections will be made, delimits unlawful acts and sets penalties. Finally, the Act requires that the Secretary of Health, Education and Welfare submit to the President, for transmittal to Congress, a comprehensive report on the administration of the Act during the previous year; specifies that federal-state cooperation is allowed; and ends by declaring null and void any state standard not identical to the federal standard.

C. Delegation of Authority

Immediately after its passage all authority granted to the Secretary of HEW by the Act was delegated to the Administrator of the Consumer Protection and Environmental Health Service. The Administrator redelegated all authority (except that of issuing and approving regulations) to the Commissioner of the Environmental Control Administration. The Commissioner delegated all authority under the Act (except the right to exempt manufacturers, products, or remit or mitigate penalties) to the Director of the Bureau of Radiological Health. This illustrates in classic style the retention of power and delegation of work that allows all levels of the Federal bureaucracy to share in the administration of a new program.

Within a few years the Act was transferred from the administrative control of the Public Health Service to the Food and Drug Administration, which reorganized and republished the entire body of rules in October 1973. The regulations are found at 21 C.F.R. §§ 1000, *et seq.* (1977).

D. Procedure of the Act

Procedurally, the reorganized rules are very complex and full discussion of them is beyond the scope of this talk. However, a few quick comments are necessary.

1. *Applies to "Dealers"*

First, the rules apply to all dealers in electronic products for which performance standards have been established, unless:

1. the products are intended only for export,
2. the products are sold only to manufacturers as components, and
3. the products are made for the government whose design is secret.

2. *Requires Reports*

Initial reports, annual reports, and a variety of special reports must be submitted to the Bureau of Radiological Health. Both manufacturer's and dealer's records must be maintained on a large number of different classes of products. Summaries of these records must be included in the annual report.

3. *Dealer Bears Costs of Replacement*

The Act specifies that each manufacturer or dealer must bear all costs of replacing or repairing any defective product and even goes to the minute detail of specifying the type style (Gothic Bold) and size (36-point) that must be put in a 3¾ by 2¼ red rectangle on a number 10 white envelope for notification of the defect. Any plan for repair, replacement, or refund of defective equipment must be approved by the Secretary of HEW in writing.

E. Substance of the Act

Substantively, the statute and rules set performance standards that must be met by certain products that emit ionizing radiation such as x-ray machines, by microwave ovens, and lasers before they can be certified for sale or import into the United States.

1. *Compliance and Penalties*

If a product is found to be out of compliance with these standards, the manufacturer or importer will be given an opportunity to bring it into compliance. If he fails to do so, he may be subject to a civil penalty of $1,000 per offense with a maximum fine of $300,000 possible for each series of related offenses. The administrative agency may remit all or some of this civil penalty if the facts warrant such action. This gives the administration power to bargain with industry. Also, the Director of the Bureau of Radiological Health, FDA has the authority to issue variances.

The substantive performance standards covering all electronic products capable of producing ionizing radiation and lasers are complex and beyond the scope of this paper. (21 C.F.R. § 1020, *et seq.*; 21 C.F.R. §

1040, *et seq.*) The performance standards dealing with microwave ovens sets 1 mW/cm² as the maximum allowable radiation 5 cm from the oven's surface prior to the oven's acquisition by the purchaser. Thereafter, the permissible radiation rises to a limit of 5 mW/cm² at the same distance. The standards also specify doorand interlock safety provisions and set forth the procedure for testing the ovens.

The rules do not specify any standards for either radio frequency radiation or for general industrial microwave radiation not produced by microwave ovens. No standards are set for any type of sonic or ultrasonic radiation. No standards are set for ionizing radiation not produced by electronic products.

III.
CONCLUSION

The Congress has delegated authority over a very great span of items and activities with this Act, yet the vast majority of its potential has not been used. Under this Act the Department of Health, Education and Welfare is given authority to regulate everything from nuclear reactors to aircraft engines. This is because every electrical part or circuit, no matter how harmless, generates electromagnetic radiation and is thus potentially subject to control. The law specifies only that the standards be "necessary for the protection of public health and safety"; there is presently no corresponding requirement that the radiation must *be harmful* in order to be regulated. Presently the Act specifically sets only a few narrow product standards, which are worked out in great detail. Perhaps as the agency administrating the Act grows more knowledgeable in the technology of microwave effects, broader and lower exposure standards will be developed to meet the realized need. The microwave oven standards are a step in this direction, but much more research is required if intelligent standards are to be set in this and other areas.

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