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AUTHORS: Michaelson SM:

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Biomedical Aspects of Microwave Exposure

SOL M. MICHAELSON

University of Rochester, School of Medicine and Dentistry, Department of Radiation Biology and Biophysics, Rochester, New York 14620

Although the exact nature of the biological effects of microwaves is not completely understood, evidence indicates that organisms exposed to microwaves at specific frequencies and power densities can experience thermal stress. Power density, duration of exposure, environmental temperature, and drugs that affect temperature regulation influence the response. Reported effects of microwave exposure on the eye, hematopoiesis, thyroid function, gonads, and central nervous and cardiovascular systems are reviewed and analyzed to indicate relevance or lack of relevance to RF and microwave exposure; to decipher the known and substantiated effects from those that are purely speculative and to provide a realistic perspective on the possible effects of exposure to this form of energy. Enactment of PL 90-602 "Radiation Control for Health and Safety Act of 1968" has evoked renewed interest in safety "Standards" for microwave exposure. The standard recommended in 1953 and subsequently adopted has been maintained with slight modification to this date. The adequacy of the originally proposed standard, namely, 10 mW/cm² has been questioned from time to time, but as in the past, there is little reason to require modification of this Standard.

Introduction

IN OCTOBER, 1968, the United States Congress passed, and former President Johnson signed, Public Law 90-602, The Electronic Products Control Law. To carry out the provisions of this law the Bureau of Radiological Health (BRH) of the United States Public Health Service was given the responsibility of setting standards (and maintaining surveillance) over all electronic products that may emit hazardous levels of electromagnetic radiation. In addition to the problem of ionizing radiation, a very large area of concern involves exposure to microwaves. This has created a resurgence of interest and concern with regard to the biologic effects and potential hazards of exposure to microwaves.

In this paper an attempt will be made to review the present state of knowledge on biologic effects of microwaves and to (1) differentiate between the known and substantiated from the speculative and unsubstantiated effects and (2) provide a realistic perspective on the nature of microwaves and the possible effects of exposure to this form of energy. Unless this is done, the tremendous potential of electromagnetic energy in the microwave range for radar, communications, biomedical, industrial, and consumer use and applications will be hampered. This is essential, since the exact nature of the biologic effects of microwaves is not completely understood. There is considerable confusion, uncertainty, and actual misinformation in this area.

Biophysics

Microwaves, a subdivision of radiowaves, are usually defined as that portion of the electromagnetic spectrum between 100 and 100,000MHz, corresponding to wavelengths in air from 3 meters to 3 millimeters.

When biologic tissues are exposed to microwaves, the radiant energy may be reflected, it may be absorbed, or it may pass through the tissue without being absorbed. The radiant energy that is absorbed is transformed into

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increased kinetic energy, thereby producing a general heating of the material. The conversion of any form of physical energy into heat is influenced by the physical properties of the absorbing material. The electrical properties of biologic tissues determine the heat development. The degree of heat produced is directly related to the rate and extent of molecular vibrations. A large part of the temperature increase from microwaves is due to the increased vibrations of polar molecules.

The electrical properties of tissues must be known for a complete understanding of the mode of interaction of electromagnetic radiation with organisms. Absorption coefficients, reflections at interfaces between different tissues, absorption of incident power, and scattering properties of tissues can be determined from this information. Electrical properties of biologic materials are related to certain composite features such as water content and macromolecular and lipid content.[1-3]

Although the electrical properties, dielectric constant, and conductivity of many tissues, cells, and macromolecular suspensions are known, the sequence of events of the physiological and biochemical reactions manifested by absorption of microwaves is not completely known.

The absorption coefficient and the depth of penetration of microwaves in tissue appear to be inverse functions of the wavelength. The dielectric constant and the specific resistance of tissue are the essential material constants which determine the development of heat in tissue. In the case of several different layers of material, the waves are in part reflected at each interface separating different tissues.

The dielectric constants and specific resistances of different tissues are known and can be used to calculate penetration depths.[4-7]

Tissue with a low water content, such as fat, is penetrated by microwaves to a considerably larger extent than tissue with high water content, such as muscle. In each case, the depth of penetration decreases rapidly with increasing frequency. For example, the wavelength of 2500 MHz provides a depth of penetration of about 9 mm in muscle. For a frequency of about 900 MHz, the depth of penetration is double that attained with 2500 MHz. The comparatively high depth of penetration in fatty tissue seems to indicate an ability of the waves to penetrate the subcutaneous fat without major energy loss and thereby to become available for heat transfer in the deep tissues. This would be true only if all the energy that reaches the muscular and other deep tissues would be absorbed by them. Partial reflection of electromagnetic waves will occur at the interface separating different media. The relative amount of the total energy, which will be reflected, is determined by the dielectric constants and specific resistance values of the different media.[2]

The total distribution of heat sources in the skin-subcutaneous-fat-muscle complex and, by summation, the total heat inputs in skin, fat, and muscle have been determined by Schwan and Li.[6,7] Under the simplifying assumption that the radiation strikes at a right angle to the surface of the body, at frequencies lower than 1000 MHz, most of the energy reaches the deeply situated tissues; the percentage of absorbed energy is nearly independent of skin and subcutaneous thickness and is about 40% of the airborne energy. Between 1000 and 3000 MHz, transition from deep heating to surface heating takes place; 20 to 100% of the airborne energy may be absorbed by the body, depending on the thickness of skin and subcutaneous fat. For frequencies above 3000 MHz, most of the radiant energy is absorbed by the skin. Thus, depth of penetration becomes so small above 3000 MHz that heat conduction rather than true penetration of radiant energy determines deep tissue temperature to a great extent. Radiation of such high frequency that heat tends to be developed at the body surface is much less apt to cause intolerable elevation of total body temperature than radiation of lower frequencies. The presence of thermal receptors in the skin, however, increases the sensitivity of this part of the body to heat loads.

The energy content for microwaves is approximately 10^{-5} electron volts (eV) per photon in contrast to x-rays or gamma rays, the energy of which is rated as thousands or millions of electron volts per photon. Since it takes about 34 eV to produce an ion pair,

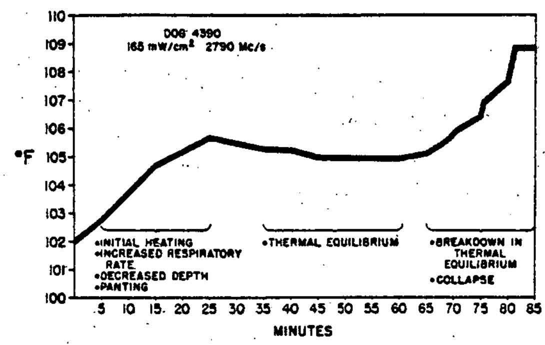

FIGURE 1. Response of dog to exposure to microwaves.

this energy level can be reached in the short-wavelength ultraviolet range and with x-rays or gamma rays. Thus, the energy value for microwaves is too low to produce ionization on a single-event basis.

Since microwaves do not cause ionization, those effects resulting from dissociation of chemical bonds, such as mutation effects, cannot be induced directly by microwaves as they can be by x-rays or gamma rays. Generally speaking, the effects of microwave exposure are not associated with the disturbing effects of ionizing radiation. The effects of microwaves are a manifestation of thermal conversion. Ionizing radiation, on the other hand, causes little thermal effect.[8]

Pathophysiology

To put the question of microwave bioeffects in its proper perspective, a critical analysis of the published literature is essential.

Any suggested harmful effects of microwave radiation exposure have been the result of exposures in excess of 100 mW/cm².

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/cm² 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. The thermal response induced by microwave exposure in an animal with thermal regulatory capability comparable to that of man (such as the dog) is characterized by three phases (Figure 1): (1) initial thermal response, (2) period of thermal equilibrium, and (3) period of thermal breakdown.[9]

In areas in which relatively little blood circulates, the temperature may rise more rapidly than in vascular parts of the body, since there is little means for the interchange of heat. Consequently, tissue damage is more likely to occur in areas where proportionately a greater rise in temperature can occur. Thus the lens of the eye is more susceptible to thermal damage, since it does not possess an adequate vascular system for the exchange of heat.

Effect on the Eyes

In man, Barron *et al.*[10] and Daily[11] did not find changes in eyes of persons working with radar. A case has been reported, however, where a technician developed bilateral cataracts while operating a radar unit in the 1500 to 3000-MHz range, with exposure to 100 mW/cm² for a 1-year period.[12] The significance of this finding has been questioned. Cogan *et al.*[13] do not believe that a microwave etiology of the cataracts was proved. Kalant[14] points out that "the lesions described are quite unlike those produced by microwaves in all the experimental studies, and the authors are careful not to claim that the lesions were caused by microwaves, but merely to urge caution." This "report gives insufficient information to permit even a guess concerning the actual intensity of exposure, and it seems improbable in the extreme that the lesions described were in fact caused by microwaves." Recurrent uveitis may have been a factor in this individual's condition.

Zaret *et al.*[15] made an extensive study of the frequency of occurrence of lenticular imperfections in the eyes of a sample of 736 microwave workers engaged in installation, operation, and development of microwave equipment and a control sample of 559 individuals of similar age grouping. Although an apparent statistical difference in the score of lens changes between the exposed and control groups existed, the difference was considered not significant from a clinical standpoint. According to Zaret *et al.*,[15] the extent of minor lenticular imperfections does not serve as a useful clinical indicator of cumulative exposure. A relationship can be established between the dose of microwave radiation delivered to the eye and the appearance of cataracts.[16] From repeated exposure at 5 watts/cm², cataracts were formed in two months. At 500 mW/cm², several months elapse prior to appearance of posterior capsular opacification; at this level, several years are required for production of formed cataracts.

Cleary and his associates[17,18] found that, although repeated subthreshold exposures may produce minimal types of lens changes, they did not appear to increase the incidence of cataracts in Army and Air Force personnel following operational exposure. An analysis of the relative incidence of lens changes in a sample of microwave workers and a control sample revealed a statistically significant increase in rate of accumulation of specific types of defects in the lenses of microwave workers. It was also noted that specific areas of microwave work specialization differ in regard to incidence of lens defects and correlations with microwave exposure parameters. Since the number of defects increased significantly with age in the control group as well as in the group of microwave workers, this process may be interpreted as indicating lens aging.

The possibility of cumulative damage to the lens from repeated "subthreshold" exposures of rabbit's eyes to microwaves has been suggested by Carpenter and associates.[19,20] Carpenter and Van Ummersen[21] note that the cumulative cataractogenic effect of microwaves "involves initiation of a chain of events in the lens, the visible and end result of which is an opacity, and that this chain of events must by initiated by an adequate power density acting for a sufficient duration of time if it is to progress to the development of an opacity. If either the power density or the duration of the irradiation is below a certain threshold value, then the damage done to the lens is not irreparable and recovery can occur, provided sufficient time elapses before a subsequent similar episode."

Most investigators agree that there is a critical intraocular temperature which must be reached before opacities develop. This temperature, as reported by various authors, ranges from 45° to 55°C. Obviously, no cumulative rise in temperature can occur if the intervals between exposures exceed the time required for the tissue to return to normal temperature. The cumulative effect to be anticipated, therefore, is the accumulation of damage resulting from repeated exposures each of which is individually capable of producing some degree of damage.[14]

According to Zaret,[22] these results do not necessarily indicate a nonthermal cumulative effect. Acute injury of the lens leads first to hydration, and this is reversible providing no lens protein denaturation has taken place despite the fact that banding, striations, and opacification are evident. Hydration of lens fibers may last for many days. If the excess water leaves the lens before denaturation has occurred, no permanent residua result. If another thermal injury intervenes, however, at a time when the lens is partially damaged, there may be a summation of effect. Baillie[23] used a hypothermic technique to investigate the postulated nonthermal mechanism for cataractogenesis from multiple microwave exposure at subthreshold levels. His data do not support the existence of a nonthermal cataractogenic property of microwave radiation. According to Baillie[23] the cataracts which developed during the course of his study can be explained only on the basis of thermal coagulation of lens protein. There is, therefore, adequate evidence to incriminate heat as the initiating mechanism leading to cataract formation during or following a single exposure to microwave radiation. This study suggests that microwave cataractogenesis is, directly or indirectly, a thermal phenomenon. At subthreshold power levels, there is still some question regarding the cumulative effects on the lens. Differences in patterns of peak pulse levels and off time between pulses may be critical factors.[24]

It should be understood that a cumulative effect is the accumulation of damage resulting from repeated exposures each of which is individually capable of producing some degree of damage. Since this has not been conclusively shown, the suggestion of cumulative effects from microwave exposure is untenable.

It is important at this point to define the cumulative effect produced by ionizing radiation to put this question in its proper perspective. It has been suggested (and there are some experimental data to support the concept) that injury incurred from exposure to ionizing radiation is cumulative. This cumulative effect is a manifestation of the *irrepairability of a certain fraction of ionizing radiation injury* which has been designated as *residual radiation injury.* This component of residual radiation injury is additive with frequency of exposures and is not dependent on intervals between exposures once the full recovery potential has been realized.[25]

Angiitis (Vasculitis)

The description of a vasculitis in a microwave oven repairman[26] warrants some discussion. The authors state that this "is the only medical and physical finding reported in the open literature that suggests a possible causal role of microwave energy from microwave ovens." It should be noted that this condition is simply an inflammation of the blood vessels of the skin induced by heat. This particular "case involved an oven repairman who turned on the unit with the door open. He subsequently filed a claim for injury specifying burns in the region of the lower abdomen and possible sterility. The latter claim was disallowed." The clinical appearance of the skin was that of a thermally induced erythema and other inflammatory changes which are typical of thermal exposure which would be expected if anyone were working in front of an oven with the door open. It should be noted further that this man was the supervisor and repairman of automated vending machines and microwave ovens for over five years in a firm specializing in such devices. Periods of exposure to microwave ovens during repair work were frequent, varying from few to no hours per day, to most of the working day. It is interesting to note that in this particular individual there was no evidence of cataract formation and retinal abnormalities, and no degenerative testicular changes. In seven additional people who had exposure to microwave energy ranging from insignificant (10 to 20 feet from microwave oven) to several hours a day of direct exposure while they repaired microwave ovens for varying periods up to five years, no gross ocular abnormalities were seen, and there were no skin or genital complaints nor were abnormalities of these areas seen.[26]

Effects on Testes

Reports of sterility in man from exposure to microwaves are questionable. Barron and associates[10,27] found no evidence of fertility changes in their human surveys. Reports of altered fertility in man even with unusually large exposures to microwaves are not available.[28] For even the most severely exposed testes, it is almost certain that thermal damage is completely reversible; irreversible damage because of abnormal temperature in the human body is not likely to occur, since death of the individual would result from other causes long before the occurrence of irreversible damage.

Testicular effects such as degeneration and reduced sperm production have been accomplished experimentally, but at very high field densities (250 mW/cm^2).

Ely *et al.,*[29] studying dogs, rabbits, and rats, attempted to estimate a safe limit of exposure in terms of the lowest power density required to cause any testicular damage in the most sensitive animal of the group. On this basis, an exposure of 5 mW/cm^2 was considered the threshold for testicular damage, for an indefinite exposure. However, the authors point out that the damage observed with such low levels of exposure is extremely slight, almost certainly fully recoverable, and in no way differentiable from that due to such commonplace factors as, for example, a hot bath. The question, therefore, is whether such damage should be legitimately considered a basis for appraisal of hazard from microwaves.[14]

Genetic Effects

There is no direct or confirmed evidence of possible genetic effects due to exposure to microwaves. Sigler *et al.*[30] reported that there was a higher incidence of children with Down's syndrome (mongolism) among fathers with prior occupational exposure to radar. This study has very questionable statistical validity, and the conclusions are subject to severe criticism.

It should be noted that the authors themselves only "suggested the relationship between mongolism and paternal radar exposure." Such an associative relationship has to be interpreted with extreme caution because of interacting variables such as simultaneous exposure to ionizing radiation and excessively high power densities. Also, it is recognized that the appearance of this congenital malformation is closely related to the age of the mother, the incidence rising more than a hundredfold with increasing age of the mother from 15 to 45 years of age. Because the estimated overall "spontaneous" incidence of Down's syndrome is about 0.15% in all births in Caucasoid populations, it is exceedingly difficult to relate any increased incidence to possible exposure history of the parent unless large numbers of well-documented cases can be correlated with precisely known exposures; this was not the case in the cited study.

Central Nervous System

The possibility that microwaves may interact with biological material without significant heating has been suggested by several Soviet investigators.[31-33]

Although some Soviet investigators describe the thermal nature of microwaves, the majority stress nonthermal or specific microwave effects at the molecular and cellular level. Studies performed in the United States generally reflect the physiologic response of the organism to the thermal burden imposed by microwaves.

A considerable body of literature has grown in the USSR on transient functional changes following low-dose (<10 mW/cm^2) microwave irradiation studied by conditional response experimentation. The Soviets have strongly and repeatedly stressed that the CNS must be considered as being moderately or highly sensitive to radiation injuries. Their conceptual basis for this view is largely centered about Pavlovian "nervism." Very briefly, this theory may be interpreted to mean that the central nervous system exerts a controlling influence over all types of reactions in the organism, including various local tissue reactions. Non-nervous reactions are considered as only of secondary importance because of the basic controlling role of the central nervous system in the whole organism. Thus, in considering microwave pathogenesis, Soviet physiologists have persistently sought the central nervous system mechanism that might be responsible for each microwave-induced phenomenon.

In general, the work of Soviet investigators in this area is subject to criticism because of limited statistical analysis of data, inadequate controls, and lack of quantification of the results. Conditional response studies intrinsically do not lend themselves to objective interpretation.

These low-level effects reported by Soviet investigators have not been confirmed outside the USSR. One of the main difficulties in confirming this Soviet work is quantification. American investigators have not been able to obtain information on how these studies were conducted, even though attempts have been made.

The importance of the difference between the Soviet and Western views is readily apparent when it is realized that practical consideration of maximum permissible exposure is based on the acceptance or rejection of nonthermal effects of microwaves as biologically significant.

One does not know how much confidence to put in the conclusions of the Soviet investigators. The results of Soviet experiments do not clearly indicate whether the changes produced by microwaves are due to generalized thermal effects or to more specific influences on particularly vulnerable tissues. The lack of precise temperature-measuring devices no doubt plays a part in the assumption of nonthermal "specific" microwave effects.

Although the Soviets recommend much lower limits than we do, there is no information presently available on how the lower limits prescribed by the Soviets are observed, if they are at all.

Osipov,[34] in a review of neurologic responses to microwave exposure, concluded that most subjective symptoms were reversible and that pathological damage to neural structures was insignificant.

Dodge,[35] in his review of the Soviet research in this area, stated: "An often disappointing facet of the Soviet and East European literature on the subject of clinical manifestations of microwave exposure is the lack of pertinent data presented on the circumstances of irradiation; frequency, effective area of irradiation, orientation of the body with respect to the source, waveform (continuous or pulsed; modulation factors), exposure schedule and duration, natural shielding factors, and whole plethora of important environmental factors (heat, humidity, light, etc.) are often omitted from clinical and hygienic reports. In addition, the physiological and psychological status of human subjects such as health, previous or concomitant medication, and mental status is also more often than not omitted. These variables, both individually and combined, affect the human response to microwave radiation."

Cardiovascular Effects

Several investigators report that exposure of animals or man may result in direct or indirect effects on the cardiovascular system.[36-39] Some authors suggest that exposure to microwaves at intensities that do not produce appreciable thermal effect may lead to functional changes. These changes are observed with acute as well as chronic exposures.[40-42]

Increased heart rate has been observed after exposure to power densities of 50 to 130 mW/cm^2 for variable periods of time ranging from 10 to 140 minutes.[37-39]

Slowing of the heart rate is reported by some Soviet investigators with low, or what they consider nonthermal, levels of microwaves,[43-45] although others have reported increased heart rate with low-level microwave exposure over the dorsal aspect of rabbits.[46,47]

These discrepancies reveal several defects in some of the experiments which should be recognized, such as frequency, power density of microwaves, duration of exposure, animal restraint, and inadequacy of statistical analysis. Review of the data in these experiments indicates that the reported differences in heart rate were chance variations influenced perhaps by circadian heart rate rhythm.

Conclusions

The only effect of microwave radiation which has been determined to be hazardous is the dielectric heating which presents a thermal hazard to the human body.

The most recent standards which designate a safety level of 10 mW/cm^2 are those recommended by ANSI Sectional Committee C 95 Subcommittee IV in 1966. The ANSI Standard C 95.4 specifies a maximum safe exposure level of 10 mW/cm^2, which is roughly a factor of 10 below thresholds of damage by thermal effects, assuming an exposure of 0.1 hour or more. The 10 mW/cm^2 level is based on thermal equilibrium conditions for whole-body radiation. Temperature rise is determined primarily by the body's ability to dissipate heat; factors affecting this would be significant in terms of the consequences of whole-body radiation. Heat dissipation capabilities are better for partial-body radiation; higher levels of irradiation would therefore be acceptable. This is the case in medical diathermy, where the levels may be at 100 mW/cm^2 or higher.

This level of 10 mW/cm^2 has been followed for the last 15 years by the U. S. Department of Defense and has been found to be completely satisfactory. No evidence has been produced which would suggest lowering this level.

The greatest need today in the assessment of biological effects of microwave exposure is to maintain a realistic perspective on the nature of microwave fields and the possible effects from exposure. The mechanisms by which cell damage is produced, the biological tolerance of the most susceptible tissues, and safe levels of intensity must be established in an organized fashion. Ultimately, a clear differentiation between hazard and biologic effect must be made.

References

1. Schwan, H. P.: Electrical Properties of Tissues and Cell Suspensions. *Advan. Biol. Med. Phys. 5:* (1957).
2. Schwan, H. P.: Biophysics of Diathermy. In *Therapeutic Heat* (S. H. Licht, ed.), pp. 55, E. Licht, New Haven (1958).
3. Schwan, H. P., and G. M. Piersol: Absorption of Electromagnetic Energy in Body Tissue—Review and Critical Analysis. *Amer. J. Phys. Med. 33:* 371 (1954).
4. Cook, H. F.: The Dielectric Behavior of Some Types of Human Tissues at Microwave Frequencies. *Brit. J. Appl. Phys. 2:* 295 (1951).
5. England, T. S.: Dielectric Properties of the Human Body for Wave-lengths in the 1-10 cm Range. *Nature 166:* 480 (1950).
6. Schwan, H. P., and K. Li: Capacity and Conductivity of Body Tissues at Ultrahigh Frequencies. *Proc. IRE 41:* 1735 (1953).
7. Schwan, H. P., and K. Li: Hazards Due to Total Body Irradiation by Radar. *Proc. IRE 44:* 1572 (1956).
8. Pollard, E. C.: The Biological Action of Ionizing Radiation. *Amer. Sci. 57:* 206 (1969).
9. Michaelson, S. M., R. A. E. Thomson, and J. W. Howland: Physiologic Aspects of Microwave Irradiation of Mammals. *Amer. J. Physiol. 201:* 351 (1961).
10. Barron, C. I., A. A. Love, and A. A. Baraff: Physical Evaluation of Personnel Exposed to Microwave Emanations. *J. Aviation Med. 26:* 442 (1955).
11. Daily, L.: A Clinical Study of the Results of Exposure of Laboratory Personnel to Radar and High Frequency Radio. *U.S. Naval Med. Bull. 41:* 1052 (1943).
12. Hirsch, F. G., and J. T. Parker: Bilateral Lenticular Opacities Occurring in a Technician Operating a Microwave Generator. *Arch. Ind. Hyg. Occup. Med. 6:* 512 (1952).
13. Cogan, D. G., S. J. Fricker, M. Lubin, D. D. Donaldson, and H. Hardy: Cataracts and Ultra-high Frequency Radiation. *Arch. Ind. Hyg. 18:* 299 (1958).
14. Kalant, H.: Physiological Hazards of Microwave Radiation: A Survey of Published Literature. *Can. Med. Assoc. J. 81:* 575 (1959).
15. Zaret, M. M., S. Cleary, B. Pasternack, M. Eisenbud, and H. Schmidt: *A Study of Lenticular Imperfections in the Eyes of a Sample of Microwave Workers and a Control Population.* Final Report Contract AF 30(602) 2215, RADC-TDR-63-125, New York University, 72 pp. (ASTIA 413 294) (1963).
16. Zaret, M. M., S. Cleary, B. Pasternack, and M. Eisenbud: *Occurrence of Lenticular Imperfections in the Eyes of Microwave Workers and Their Association with Environmental Factors.* Progress Report Contract AF 30 (602)2215, RADC-TN-61-226, New York University, 109 pp. (ASTIA 266 831) (1961).
17. Cleary, S. F., and B. S. Pasternack: Lenticular Changes in Microwave Workers. A Statistical Study. *Arch. Environ. Health 12:* 23 (1966).
18. Cleary, S. F., B. S. Pasternack, and G. W. Beebe: Cataract Incidence in Radar Workers. *Arch. Environ. Health 11:* 179 (1965).
19. Carpenter, R. L.: Studies on the Effects of 2450 Megacycle Radiation on the Eye of the Rabbit. In *Proc. Third Tri-Service Conf. Biol. Effects Microwave Energy,* RADC-TR-59-140, p. 279 (1959).
20. Carpenter, R. L., D. K. Biddle, and C. A. Van Ummersen: Biological Effects of Microwave Radiation with Particular Reference to the Eye. In *Proc. Third Intern. Conf. Med. Electronics. London. 3:* 401 (1960).
21. Carpenter, R. L., and C. A. Van Ummersen: The Action of Microwave Radiation on the Eye. *J. Microwave Power 3:* 1 (1968).
22. Zaret, M. M.: Comments on Papers Delivered at Third Tri-Service Conference on Biological Effects of Microwave Radiation. *Proc. Third Annual Tri-Service Conf. Biol. Effects Microwave Rad. Equip.,* p. 334, RADC-TR-59-140 (1959).
23. Baillie, H. D.: *Thermal and Non-thermal Cataractogenesis by Microwaves.* Presented at the Symposium on the Biological Effects and Health Implications of Microwave Irradiation, Richmond, Virginia, September, 1969.
24. Roth, E. M.: Microwave Radiation. In *Compendium of Human Responses to the Aerospace Environment* (E. M. Roth, ed.), Vol. 1, Sect. 1, NASA CR-1205(1) (1968).
25. Blair, H. A.: The Constancy of Repair Rate and of Irrepairability during Protracted Exposure to Ionizing Radiation. *Ann. N.Y. Acad. Sci. 114:* 150 (1964).
26. Rose, V. E., G. A. Gellin, C. H. Powell, and H. G. Bourne: Evaluation and Control of Exposures in Repairing Microwave Ovens. *Amer. Ind. Hyg. Assoc. J. 30:* 137 (1969).
27. Baron, C. I., and A. A. Baraff: Medical Considerations of Exposure to Microwaves (Radar). *J. Amer. Med. Assoc. 168:* 1194 (1958).
28. Rosenthal, D. S., and S. C. Beering: Hypogonadism after Microwave Radiation. *J. Amer. Med. Assoc. 205:* 245 (1968).
29. Ely, T. S., D. E. Goldman, J. Z. Hearon, R. B. Williams, and H. M. Carpenter: *Heating Characteristics of Laboratory Animals Exposed to Ten-centimeter Microwaves,* U.S. Navy, Naval Medical Research Institute, Bethesda, Md. Research report. Project NM 001 056.13.02, Vol. 15, p. 77 (1957).
30. Sigler, A. T., A. M. Lillienfeld, B. H. Cohen, and J. E. Westlake: Radiation Exposure in Parents of Children with Mongolism (Down's Syndrome). *Johns Hopkins Hosp. Bull. 117:* 374 (1965).
31. Dodge, C., and S. Kassel: *Soviet Research on the Neural Effects of Microwaves,* LC-ATD-66.-133, Library of Congress, Washington, D. C. (1966).
32. Presman, A. S.: The Effect of Microwaves on Living Organisms and Biological Structures. *Usp. Fiz Nauk. 86:* 263 (JPRS 33054) (1965).
33. Turner, J. J.: The Effects of Radar on the Human Body; Results of Russian Studies on the Subject. (Summary based on A. A. Letavet and Z. V. Gordon, eds., *The Biological Action of Ultra-High Frequencies,* JPRS-12471, Washington, D. C.) (1962).
34. Osipov, Yu. A.: *Occupational Hygiene and the Effects of Radiofrequency Fields on Workers.* Izd. Meditsina (Leningrad). (ATD 66.-133, Library of Congress, Washington, D. C.), p. 104 (1965).
35. Dodge, C.: *A Review of Clinical Manifestations of Microwave Exposure to the CNS.* Presented at the Symposium on the Biological Effects and Health Implications of Microwave Irradiation, Richmond, Virginia, September, 1969.
36. Cooper, T., M. Jellinek, and T. Pinakatt: The Effect of Pyridoxine and Pyridoxal on the Circulatory Response of Rats to Microwave Irradiation. *Experientia 21:* 28 (1965).
37. Cooper, T., T. Pinakatt, M. Jellinek, and A. W. Richardson: Effects of Adrenalectomy, Vagotomy and Ganglionic Blockade on the Circulatory Response to Microwave Hyperthermia. *Aerospace Med. 33:* 794 (1962).
38. Marks, J., E. T. Carter, D. T. Scarpelli, and J. Eisen: Microwave Radiation to the Anterior Mediastinum of the Dog. *Ohio State Med. J. 57:* 274 (1961).
39. Subbota, A. G.: Changes in Respiration, Pulse Rate and General Blood Pressure during Irradiation of Animals with a UHF Field. *Tr. Voenno. Med. Akad. (Ref. Zhur. Biol.* 1959, No. 59927) *73:* 73 (1957).
40. Gordon, Z. V.: The Problem of the Biological Action of UHF. In *The Biological Action of Ultra-High Frequencies* (A. A. Letavet and Z. V. Gordon, eds.), p. 5, Acad. Med. Sci. (Moscow), JPRS 12471 (1960).
41. Gorodetskaia, S. F.: The Influence of an SHF Electromagnetic Field on the Reproduction, Composition of Peripheral Blood, Conditioned Reflex Activity, and Morphology of the Internal Organs of White Mice. In *The Biological Action of Ultrasound and Super-High Frequency Electromagnetic Oscillations* (A. A. Gorodetskiy, ed.), p. 80, Acad. of Sci. (Kiev), JPRS 30860 (1964).
42. Presman, A. S., Yu. I. Kamenskiy, and N. A. Levitina: The Biologic Effect of Microwaves. *Usp. Sovrem. Biol. 51:* 84 (1961). (ATD P 65-68. Library of Congress, Washington, D. C.)
43. Kevork'yan, A. A.: Working with Ultrahigh Frequency Impulse Generators from the Standpoint of Labor Hygiene. *Gigiyena i Sanit. 4:* 26, 1948. (ATD P 65-68. Library of Congress, Washington, D. C.)
44. Sadchikova, A. A., and A. A. Orlova: Clinical Picture of the Chronic Effects of Electromagnetic Microwaves. *Ind. Hyg. Occup. Dis. (USSR) 2:* 18 (1958).
45. Tyagin, N. V.: Changes in the Blood of Animals Subjected to a UFH Field. *Tr. Voenno. Med. Akad. (Ref. Zhur. Biol.,* 1959, No. 59923), *73:* 116 (1957).
46. Presman, A. S., and N. A. Levitina: The Non-thermal Effect of Microwaves on the Systolic Rhythm of Animals; Report I: The Effect of Non-pulsed Microwaves. *Byul. Eksperim. Biol. i Med. 53:* 39 (1962).
47. Presman, A. S., and N. A. Levitina: The Nonthermal Effect of Microwaves on the Rhythm of Cardiac Contractions in Animals. Report II. Investigations of the Effect of Pulsed Microwaves. *Byul. Eksperim. Biol. i Med. 53:* 41 (1962).

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