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TASK FORCE ON RESEARCH PLANNING

IN ENVIRONMENTAL HEALTH SCIENCE

Physical characteristics of Microwaves + lasers Biological Hazards

Subtask Force on Physical Factors in the Environment

BACKGROUND DOCUMENT

Lasers and Microwaves

Part I

"CONSIDERATIONS IN THE EVALUATION OF THE BIOLOGICAL EFFECTS OF EXPOSURE TO MICROWAVE RADIATION"

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Part II

Lasers, to follow

SUB-TASK FORCE ON PHYSICAL FACTORS IN THE ENVIRONMENT

Considerations in the Evaluation of the Biological Effects of Exposure to Microwave Radiation*

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Introduction

The development of radar equipment for military applications during World War II resulted in the introduction of a new range of electromagnetic radiation frequencies into man's environment - microwave radiation. Until that time electromagnetic radiation had been restricted by the available technology primarily to long wavelength radio waves and to the very short wavelength regions of the infrared, visible and ultraviolet light and x-radiation. Microwaves, which are sometimes referred to as super-high frequency electromagnetic radiation (SHF), encompass the wavelength band of from 1 mm to 1 m, adjacent to the ultra-high frequence band (UHF) of from about 1 m to 100 m. Practically all types of electromagnetic communications systems including radio and television signals are operated in either the UHF or the SHF bands.

Initially the applications of microwave radiation were limited to military radar systems but the use of radar for aerial and shipboard navigational systems is now commonplace in commercial and private operations. The unique ability of some frequencies of microwave radiation to penetrate deeply into solid media thus producing internal heating has resulted in a wide variety of new applications of this radiation. In addition to the well-known medical use of microwaves for diathermy treatment, more recent applications include drying and freeze drying, sealing, cooking, reheating, thawing, moisture leveling and sterilization. Future applications may include the use of microwave ionized gases for chemical processing, space propulsion, controlled nuclear fusion, hovering vehicle propulsion (microwave powered helicopters), microwave motors, wave guide vehicle transport, and radiation beam "wireless" power transmission[1].

To illustrate the prevalence of microwave generating equipment it is estimated that almost 100, 000 microwave ovens are currently being used in homes, restaurants, hospitals and automatic food vending facilities. Due to the aforementioned applications of microwave radiation for the processing of food and other materials there will most likely be widespread use of microwaves in industry in the near future. In view of the introduction of microwave generators to public usage and the recent passage of Public Law 90-602, the "Radiation Control for Health and Safety Act of 1968", the implications of population exposure must be considered in light of the available information concerning the biological effects of microwave exposure. Particular attention should be focused on the type of exposures most likely to be encountered in the present and future microwave environment; namely, intermittent or continuous low-level exposures to a number of UHF and SHF radiation frequencies. The purpose of this communication is to review the available information on the biological effects of microwave radiation in an attempt to evaluate its adequacy for the determination of permissible microwave exposure levels.

The Microwave Problem

Following World War II high power output radar equipment operated primarily in the SHF band was developed for military applications. Radars with average power outputs in excess of 1 Kw were capable of producing microwave fields with power densities sufficient to cause detectable heating of the skin at distances of several hundred feet from the radar antenna. Both military and industrial organizations were aware of the potential biological hazards of microwave exposures at such levels. A Tri-Service Committee was formed in the United States in 1956 which consisted of representatives of the Army, Air Force and Navy. This committee was charged with the task of evaluating the potential biological hazards of microwave exposure in an effort to establish safe levels of microwave exposure for military personnel. As an outcome of an evaluation of the available information on human exposures and information obtained from research conducted with animals, 10 milliwatts (mw)/cm^2 was recommended as the exposure limit. This limit was primarily based on two lines of reasoning. First, it had been theoretically and experimentally determined that continuous whole body exposure of a human to this power density would result in a maximum equilibrium body temperature rise of 1°C - a level considered tolerable on a long term basis without risk of irreversible damage[2]. Secondly, a number of experimental investigations of the effects of microwave exposure in animals indicated that irreversible tissue damage resulted from exposures at power densities of approximately 100 mw/cm^2, and thus applying a safety factor of 10, the level of 10 mw/cm^2 was suggested.

The results of animal experimentation and theoretical and experimental data pertinent to the absorption of microwave radiation in the human body have been summarized in a number of review articles (see e.g. Moore[3] and Schwan[4]). In general, the results of experiments carried out in this country suggested that thermal damage was the primary effect of excessive exposure to microwave radiation. The thermal effects varied from generalized febrile reactions in the case of whole body exposure in animals[5], to specific effects upon the hematopoietic system[6], the testes[5], and the lens of the eye[7]. The physiological alterations produced by elevating the temperature of the organism by absorption of microwave radiation are macroscopically indistinguishable from changes produced by fever of any origin. Generalized stress reactions involving the pituitary-adrenal response are noted, including increases in leukocytes and decreases in eosinophils and lymphocytes[6]. At fatal levels of exposure the symptoms include myocardial necrosis, hemorrhages in the lungs, liver, gut and brain, and generalized degeneration of all body tissues. The effects of non-fatal microwave induced hyperpyrexis have generally been assumed to be reversible with the exception of lenticular changes. At levels of approximately 100 mw/cm^2 cataractous lesions are induced in the lens by acute or fractionated microwave exposure[7]. Although in the case of cataract formation there is some evidence to suggest that the effect is not strictly thermal[7], it appears to be generally agreed that thermal effects predominate at exposure levels of greater than 10 mw/cm^2. Based upon a thermal damage criteria, the United States of America Standards Institute has adopted the following standard: "For normal environmental conditions and for incident electromagnetic energy of frequencies from 10 megahertz (MHz) to 100 gigahertz (GHz), the radiation protection guide is 10 mw/cm^2 as averaged over any possible 0.1 hour period. This means the following:

Power density: 10 mw/cm^2 for periods of 0.1 hour or more;

Energy density: 1 mwh/cm^2 during any 0.1 hour period.

This guide applies whether the radiation is continuous or intermittent"[9]. The specification that the energy density shall be limited to 1 mwh/cm^2 during any 0.1 hour period limits the temperature rise in a body exposed to a microwave field to less than 1°C but permits exposure to power density levels in excess of

10 mw/cm^2 for suitable short durations.

The microwave exposure standards accepted by the U.S. military and many industrial microwave users are generally similar to the USASI standard. The Bell Telephone Laboratories has adopted a more conservative limit which states, "(1) Power levels in excess of 10 mw/cm^2 are potentially hazardous, and personnel must not be permitted to enter areas where major parts of the body may be exposed to such levels. (2) Power levels between 1 and 10 mw/cm^2 are to be considered safe only for incidental, occasional, or casual exposure, but are not permissible for indefinitely prolonged exposure"[10].

The applicability of these microwave exposure standards to non-occupational, non-military exposure involves the consideration of a number of factors. It is, of course, obvious that as in the case of exposure standards for ionizing radiation different criteria should perhaps be applied to exposure of the general public as contrasted to military or industrial exposure due to the difference in the number of people exposed and the differences in the distributions of age and states of health. This suggests that factors such as genetic effects and somatic alterations leading to the induction of neoplastic or other diseases or impairments must be considered as well as more subtle effects such as behavioral changes and synergistic effects. Whereas the presently available information does not demonstrate the existence of such effects of microwave exposure, sufficient data is not available to definitely rule them out. In some cases, to be subsequently discussed, there have been data reported in the literature which have been interpreted as suggesting that such effects do, in fact, exist. It should be mentioned that most of the presently available data are, to a certain extent, of limited applicability due to the fact that most of the experiments were conducted with animals and not with humans; they were performed at power densities much greater than 10 mw/cm^2; and, they were mainly conducted with S(10cm) and X (3cm) band microwave frequencies. If the present and future microwave environment is confined to the S and X bands at which frequency specific biological effects have not as yet been detected, the chances of producing bizarre or unknown biological effects should be minimal.

To evaluate the possible significance of frequency specific, low power density, (non-thermal) microwave effects, the basic modes of interaction of microwaves with biological media must be considered. Microwave radiation may be represented as a traveling wave consisting of transverse electric and magnetic oscillating fields; the amplitude of the oscillations is directly related to the power density of the field. There will be a significant energy exchange from the electromagnetic field to the medium whenever the forces resulting from the interaction of the electric and magnetic fields of the molecules of the medium and the microwave field are sufficient to alter the kinetic or potential energy of the molecules. It is generally assumed that the permanent or induced magnetic moments of biological molecules are of such small magnitude that energy exchange by this mechanism can be neglected in comparison to exchange between the electric fields. It should be noted, however, that there are biological molecules such as hemoglobin which contain ferromagnetic atoms, so that interactions with the magnetic component of the microwave field may not always be negligible. There is extensive data indicating that static magnetic fields do produce alterations in biological systems[11].

Neglecting the magnetic component of the microwave field, the energy exchange will occur between the electric fields. The electric field of molecules in the medium may be due to permanent dipole moments or to polarizability under the influence of the microwave field, or to both in conjunction. Since the permittivity of a dielectric material is a direct measure of the number of permanent and induced dipoles, it is found that energy absorption in biological media is a function of the permittivity. Energy may also be transferred from the microwave field to electrons in conduction bands, so that energy absorption is also a function of the conductivity of the medium. A consequence of the mode of energy exchange between biological media and microwaves is that tissues such as muscle which have a high water content will have relatively high permittivities and conductivities and will absorb larger amounts of energy from a microwave field than tissues such as fat or bone which have a low conductivity and permittivity. This phenomenon is of importance in microwave diathermy, since selective heating of tissues is possible.

On a molecular scale, the mode of energy exchange results in vibrational and rotational motion of polar molecules by interaction with the impressed electric field of the microwave radiation. To obtain an idea of the magnitude of the energy exchange, the process may be considered from a quantum mechanical point of view and the quantum energy associated with a microwave field calculated. The energy quanta associated with, for example, a 3 cm microwave is 4×10^{-5} ev as compared with approximately 2-3 ev for visible light and 10^{6} ev for gamma photons. Since the ionization potentials of atoms are in the range of several ev microwaves do not produce ionization but instead may produce excited rotational or vibrational energy levels of the molecules in a medium. The net effect, therefore, of the interaction of a microwave field with tissues composed of a wide variety of molecular species is an increase in temperature from molecular vibration and rotation.

The response of biological molecules to the impressed microwave field depends upon their charge distribution, molecular weight, and shape - factors which also determine the relaxation time required for such molecules to alter their orientation in response to the field. Energy exchange will be a function of the impressed frequency and the molecular species. This phenomenon serves as the basis for the technique known as dielectric dispersion which is used in molecular biology to determine the relationship of the dielectric constants of proteins, amino acids, and peptides to dipole moments, rotary diffusion coefficients, and relaxation times. Dielectric dispersion studies on proteins, peptides and amino acids have indicated that characteristic relaxation times cover the range from 5×10^{-11} sec for glycine and 250×10^{-8} sec for horse serum γ-pseudoglobulin[12]. Converting these relaxation times to frequencies, the corresponding frequency range is from 3.3 GHz to 6.6 KHz - a region that almost completely encompasses the UHF and SHF bands of electromagnetic radiation.

The results of dielectric dispersion studies suggest the possibility of frequency specific effects of UHF and SHF radiations, although it is not evident from the available data that such effects lead to irreversible denaturation of proteins in the case of in vivo irradiations. However, bovine gamma globulin and equine serum cholinesterase have shown specific changes (denaturations) upon irradiation in the vicinity of 13.12 MHz[13]. Similar effects on the structural properties of proteins (human gamma globulin) were reported by Bach[14], although the problem of temperature control introduced uncertainties in the interpretation of his data.

There does not appear to be any available data on frequency specific effects in cell systems. Such studies might be utilized to detect denaturation effects on specific molecular systems as a function of frequency. Since viable cells are in a state of continuous synthesis, they would contain protein and nucleic acid molecules in all stages of synthesis at any given time. These partially synthesized protein or nucleic acid molecules should have wide distributions of molecular weight, size, shape, and charge, with molecular relaxation times which might correspond to the frequency of the applied field. If polar molecules or polarizable molecular complexes within the cell interact with an electric field of sufficient magnitude to produce orientational changes, these effects might be expected to interfere with the synthetic processes of the cell. Heller and Teixeira-Pinto[15] have observed intracellular orientation of subcellular particles and were able to produce chromosomal aberrations, including linear shortening, pseudochiasmata, amitotic division, bridging, and irregularities in the chromosomal envelope. These effects were produced at a frequency of 27 MHz under conditions such that the temperature rise did not affect the viability of the organism. On the basis of the available evidence, it was not possible to precisely determine the role of temperature effects. Lystsov et al[16] using 9.37 GHz radiation concluded that in Bacillus subtilis there was no direct non-thermal effect on the genetic apparatus of the cell but there appeared to be alterations in metabolic enzymatic processes. Nyrop[17] found that a 20 MHz field, modulated at frequencies of from 10 - 100 KHz, resulted in the inactivation of Bacterium coli and foot-and-mouth disease virus at temperatures significantly below those required for thermal inactivation. The virus inactivated by the electric field was found to lack antigenic activity, a different effect from that observed for the thermally inactivated virus. Nyrop also demonstrated that tissue cultures could be killed at field strengths of 22 v/cm without raising the temperature of the culture above 30°C[7]. In studies of the effects of low power density irradiations of Escherichia coli B at 136 GHz it was found that the rate of cell division was slowed down, and specific metabolic processes, occurring during the early part of the life span, were inhibited[18]. In another series of experiments, lymphoblastoid transformation of lymphocytes in vitro was induced by 10 cm microwave radiation at low or relatively non-thermal power densities[19]. Fragmented nuclei were noted among the transformed cells with bridges joining separated parts of nuclear material. In some cases the nuclei were completely broken down into small fragments and vacuolization was also detected. These studies tend to suggest non-thermal microwave fields at various frequencies interact with intracellular moieties to alter metabolic and/or genetic processes. Interpretation of the significance of these findings is difficult since mechanisms are not specified. In vivo cellular transformations were also detected by Valtonen[20] who reported the appearance of giant mast cells in the peritoneal fluid of the rats following low power density microwave radiation. It is suggested that the formation of the giant mast cells is a result of a degenerative change in the mast cell and is a non-thermal effect of microwave irradiation. Moressi[21] on the other hand, found that microwave irradiation at 2450 MHz of mouse sarcoma 180 cells did not result in cellular destruction that differed significantly from thermal damage.

The orientation of micron size particles by microwave radiation has been studied by several investigators. Various particles including iron filings, starch particles, colloidal carbon particles, oil droplets, mammalian erythrocytes, macrophages and various bacteria were studied. In general, it was found that asymmetric particles were oriented in the field and the orientation (with respect to the lines of force of the electric field) was a function of the frequency of the field, age of the particle (in the case of biological materials) and the permittivity of the suspending medium[22]. It has been determined that for particles such as biological cells, field strengths in excess of 100 v/cm are required to produce such effects and for steady state field strengths of this magnitude thermal effects will predominate. The effects of cellular orientations resulting from pulsed microwave fields of low average power density but high instantaneous field strengths are, however, not presently known[4].

On the basis of the available data on the effects of low power density (i.e. 10 mw/cm^2) microwave irradiation of molecular and cellular systems it is not possible to rule out the existence of frequency specific non-thermal effects. If such effects are induced by low level exposure to microwave radiation, it might be anticipated that they would be manifested in effects on the organ system or organism level, and, therefore, they would be detectable in human or experimental animals, even though, they would not result in as marked changes typical of thermal damage. As previously mentioned, most studies on animals conducted in the United States have been designed to detect the effects of tissue hyperthemia and have generally indicated that such effects are not detected at levels below 10 mw/cm^2. However, a number of studies of the effects of low-level chronic microwave exposure of humans and animals have indicated effects, in particular, on the central nervous system.

The effect of UHF electromagnetic fields on the nervous system of animals has been the object of numerous investigations. In a review of such effects Livshits[23] suggests that the effect of UHF radiation on the nervous system is primarily due to interactions at the cellular level. Due to the role of the nervous system in the functioning of the cardio-vascular system, many of the effects of microwaves on the latter system have been attributed to direct interaction with the central nervous system. The implied effects of microwaves on the nervous system of animals include: alterations in conditioned reflexes, vagomimetic action on the heart, stimulation of the parasympathetic and inhibition of the sympathetic nervous system, alterations in heart rhythm and diameter of blood vessels, structural alterations in the synapses of the vagus nerve, altered sensitivity to drug stimuli, reduction in diuresis, altered stomach secretion, and various metabolic effects[23]. Although the power densities at which these effects were induced are not given, it is indicated that the UHF fields were too weak and geometrically too small to produce generalized temperature rises. In another series of investigations of the effect of electromagnetic fields on the central nervous system, Kholodov[24] reported specific non-thermal effects of microwaves. These effects include changes in conditioned reflexes, alterations in sensitivity to light, sound, and olefactory stimuli, changes in the structure of skin receptors of the digestive and blood-carrying systems, alterations in the biocurrents of the cerebral cortex, reversible structural changes in the cerebral cortex and the diencephalon, and the appearance of various vegetative reactions. Changes in the rhythm of the dog heart were reported by Presman and Levitina[25] following exposure to microwave fields of 5-10 mw/cm^2. Irradiation of the ventral side of rabbits caused a decrease in the heart beat as contrasted to an increased heart rate following radiation of the dorsal side and the head. The effect was attributed to central nervous system stimulation as a result of irradiation of the head as contrasted to stimulation of peripheral receptors and the autonomic nervous systems from ventral irradiations.

Clinical manifestations of the effects of chronic low power density microwave irradiations on Russian microwave workers have been reported by Letavet and Gordon[26]. The effects tend to indicate that the central nervous system is the organ system most sensitive to microwave exposure. The reported effects of chronic occupational exposure of humans to microwave radiation include: bradycardia, disruption of the endocrine-humeral process, hypotension, intensification of the activity of the thyroid gland, an exhausting influence on the central nervous system, a decrease in sensitivity to smell, and an increase in the histamine content of the blood. In addition to these findings there was a high incidence of subjective complaints among the 525 microwave workers examined during the course of the study. These complaints included: increased fatigability, periodic or constant headache, extreme irritability, and sleepiness during work.

Clinical studies of microwave workers conducted in the United States by Daily[27] and by Barron and Baraff[28] indicated, in contrast to the finding of Letavet and Gordon[26], no acute, transient, or cumulative physiological or pathological changes which could be attributed to microwave exposure. Statistical analyses of the clinical findings are not reported in either the Russian or the U. S. studies.

Based on the findings of Letavet and Gordon[26] the following permissible limit for exposure to microwave radiation has been established in the U.S.S.R.: "The microwave radiation intensity in areas where personnel are required to be present should not exceed the following maximum permissible values:

a. In the case of irradiation during the entire working day -- no more than 0.01 mw/cm^2.

b. In the case of irradiation for no more than two hours per working day - no more than 0.1 mw/cm^2.

c. In the case of irradiation for no more than 15 to 20 minutes per working day - no more than 1.0 mw/cm^2 (In this case the use of protective goggles is mandatory.)"[26].

There have also been reports in the Western literature of suspected central nervous system effects produced by low level microwave exposure. Frey has found that the perception of sound can be induced in humans irradiation with microwave radiation at levels of less than 10 mw/cm^2 and changes in the heart rate of monkeys are also indicated[29]. It was suggested that the auditory response might be a direct non-thermal effect on the nervous system but the studies of Sommer and von Gierke indicate that the effect may be due instead to electromechanically induced vibrations in tissue coupled with normal reception in the cochlea[30]. Frey also has detected evoked electrical potentials in the brain stem of cats induced by irradiation with pulse-modulated UHF radiation[31]. The threshold power density reported is 30 mw/cm^2 average and 60 mw/cm^2 peak power. The potentials are ascribed to a direct interaction of UHF radiation with neural tissue. Exposure of birds to non-thermal power densities has been shown by Tanner and coworkers to result in alterations in behavioral patterns. The type of reaction was found to depend upon the surface irradiated with dorsal irradiation producing the most marked effects[32]. Results of studies by Korbel and Thompson[33] of the effects of low intensity UHF radiations on rats suggested that behavioral effects are produced by non-thermal levels of exposure.

On the basis of the foregoing clinical and experimental indications of neural effects of electromagnetic radiations in the UHF and SHF bands, such effects are difficult to ignore, even though there is uncertainty regarding the power densities required to elicit these effects and even though many of these effects are reversible and have not been deomonstrated to lead to permanent damage. The existence of neural effects at non-thermal levels of microwave exposure has been questioned, since, as noted by Schwan[4], physical mechanisms have not been specified. A possible mechanism may however be suggested by recent advances in the theory of nerve excitation and conduction. On the basis of three new axon membrane properties: negative fixed surface charge, birefringence changes, and infrared emission, Wei[34] has suggested a physical model of nerve excitation and conduction based on the arrangement of dipoles in layers on the surface of the axonal membrane. Alteration of the outer dipole layer will permit transfer of sodium ions across the membrane and will lead to "nerve excitation". Although the structure of the dipoles is not known, it is clear from the theory of dielectric dispersion that an alternating electric field (e.g. UHF or SHF) can interact with molecular dipoles to an extent dependent upon the relaxation time of the dipoles and the frequency of the applied field. Re-orientation of the dipoles could alter the dipole potential at the membrane surface resulting in a change in the threshold for excitation or conduction as detected by Frey[31] and others. Since these dipole layers might not be uniform throughout the nervous system, the effect might be frequency dependent, or conversely, at a particular frequency, specific areas of the nervous system might be affected. Further experimental and theoretical work is, of course, necessary to evaluate the validity of this mechanism of interaction but it serves to illustrate the fact that because of present lack of understanding concerning the basic neural processes, it is necessary to continue the investigation of microwave effects at low power densities.

Conclusions and Recommendations

The available theoretical and experimental data appear to adequately explain the thermal effects of exposure to microwave and UHF radiations and it is possible to delineate lethal levels of exposure as well as levels that will produce irreversible changes such as cataracts. The effects of exposures at power densities of less than 10 mw/cm^2 - non-thermal irradiations - are at present uncertain. The significance of the clinical studies reported in the Russian literature is difficult to assess since the power densities are not available and no objective statistical analysis is presented[35]. In controlled statistical studies of the incidence of sub-cataractous lens changes[36] and cataracts[37] in radar workers it was determined that although there was no statistically significant increase in cataract incidence, there were significant increases in certain types of lens changes which were correlated with the type of radar work performed. Accurate exposure levels could not be determined but it was estimated that the power densities were generally less than 100 mw/cm^2. These studies illustrated the feasibility of a controlled statistical study of the epidemiology of microwave-induced lens changes. Experimental results in animals irradiated at non-thermal levels are again difficult to evaluate, but tend to suggest that microwave radiation can interact with the central nervous system to produce a number of effects, including changes in the cardio-vascular system. In general, these effects appear to be reversible, although some clinical evidence to the contrary exists[26]. Interpretation of neural effects of microwaves is difficult because of a lack of knowledge concerning basic mechanisms of interaction, but recent work on nerve conduction may provide the necessary mechanisms. Consideration of the significance of these non-thermal effects - if they, in fact, do exist suggests that they may pose an indirect threat to public safety (for example, functional alterations might be induced in airline pilots during landing or take-off).

In view of the many uncertainties, additional research should be performed in the area of non-thermal effects of UHF and SHF radiations. The research should be carried out at several levels including:

a. molecular research - to determine the basic mechanisms of alteration of molecular structure as a function of power density and frequency;

b. cellular research - to investigate the effects of non-thermal irradiations on metabolic and genetic mechanisms;

c. animal experimentation - to detect effects on the central nervous system by direct measurement of induced potentials and effects on conditioned responses and reaction times;

d. epidemiological investigations - to answer the vital question of whether or not the clinical effects reported in the Russian literature (and serving as the basis of the Russian exposure limits) can be detected in a properly designed statistical study of microwave workers and appropriately selected control groups.

The results of studies of the type mentioned above would be of great value in determining what levels of UHF and SHF could be tolerated in the general environment without discomfort or risk to humans.

References

1. Okress, E. C.: Microwave Power Engineering. Vol. 2, Academic Press, New York (1968).

2. Schwan, H. P. and Li, K.: Hazards Due to Total Body Irradiation by Radar. Proc. IRE, 44, 1572 (1956).

*3. Moore, W., Jr.: Biological Aspects of Microwave Radiation - A Review of Hazards. U. S. Dept. Health, Education and Welfare, P.H.S. Report TSB 4, (1968).

*4. Schwan, H. P.: in Okress Microwave Power Engineering. Vol 2, 215, Academic Press, New York (1968).

5. Ely, T. S., Goldman, D. E., and Hearon, J. Z.: Heating Characteristics of Laboratory Animals Exposed to Ten-Centimeter Microwaves. IEEE Trans. Biomed. Eng., BME-11, 123, 1964.

6. Michaelson, S. M., et al: The Hematologic Effects of Microwave Exposure. Aerospace Med., 824, (1964).

*7. Carpenter, R. L. and Van Ummersen, C. A.: The Action of Microwave Power on the Eye. Jnl. of Microwave Power 3, 3 (1969).

8. Kalant, H.: Physiologic Hazards of Microwave Radiation: A Survey of Published Literature. Can. M.A.J. 81, 575 (1959).

9. Safety Level of Electromagnetic Radiation with Respect to Personnel. United States of America Standards Institute (USASI) C95.1 (1966).

10. Weiss, M. M., and Mumford, W. W.: Microwave Radiation Hazards. Health Physics 5, 160 (1961).

11. Barnothy, M. F.: Biological Effects of Magnetic Fields. Plenum Press, New York (1964).

12. Neurath, H. and Bailey, K.: The Proteins. Vol 1 Part B, 698, Academic Press, New York (1953).

13. Final Report on Biological Effects of R-F on Macromolecules DA18-108-CML-7061, U. S. Army Chemical Center, Maryland (1962).

14. Bach, S. A., Luzzio, A. J., and Brownell, A. S.: Effects of Radio Frequency Energy on Human Gamma Globulin. Biological Effects of Microwave Radiation. Vol 1 Plenum Press, New York (1961).

15. Heller, J. H. and Tiexeira-Pinto, A. A.: A New Physical Method of Creating Chromosomal Aberrations. Nature 183, 905 (1959).

16. Lystsov, V. N., et al: Effect of Centimeter Radiowaves on Vegetative Cells, Spores, and Transforming DNA. Biofizika, 10, 114 (1965).

17. Nyrop, J. E.: Specific Effect of High-Frequency Electric Current on Biological Objects, Nature, 157, 51 (1946).

18. Webb, S. J. and Dodds, D. D.: Inhibition of Bacterial Cell Growth by 136 gc Microwaves. Nature 218, 375 (1968).

19. Stodolnik-Baranska, W.: Lymphoblastoid Transformation of Lymphocytes in vitro after Microwave Irradiation. Nature 214, 102 (1967).

20. Valtonen, E. J.: Giant Mast Cells - A Special Degenerative Form Produced by Microwave Radiation. Exptl Cell Res. 43, 221 (1966).

21. Moressi, W. J.: Mortality Patterns of Mouse Sarcoma 180 Cells Resulting from Direct Heating and Chronic Microwave Irradiation. Exptl Cell Res. 33, 240 (1964).

22. Teixeira-Pinto, A. A. et al: The Behavior of Unicellular Organisms in an Electromagnetic Field. Exptl Cell Res. 20, 548 (1960).

23. Livshits, N. N.: The Role of the Nervous System in Reactions to UHF Electromagnetic Fields. Biofizika 2, 372 (1957).

24. Kholodov, Y. A.: The Effects of Electromagnetic Fields on the Central Nervous System. Priroda 4, 104 (1962).

25. Presman, A. A. and Levitina, N. A.: Non-thermal Effect of Microwaves on the Rhythm of Systoles in Animals. Biul. Eksper. Biol. Med. 53, 41 (1962).

26. Letavet, A. A. and Gordon, Z. V.: The Biological Action of Ultrahigh Frequencies. Acad. of Med. Sci. U.S.S.R. Moscow (1960).

27. Daily, L. E.: Clinical Study of Results of Exposure of Laboratory Personnel to Radar and High Frequency Radio. U.S. Nav. M. Bull. 41, 1052 (1943).

28. Barron, C. I., and Baraff, A. A.: Medical Considerations of Exposure to Microwaves (Radar). J.A.M.A. 168, 1194 (1958).

29. Frey, A. H.: Some Effects on Human Subjects of Ultrahigh-Frequency Radiation. The Amer. Jnl. Med. Elect. 2, 28 (1963).

30. Sommer, H. C. and von Gierke, H. E.: Hearing Sensations in Electric Fields. Aerospace Med. 35, 834 (1964).

31. Frey, A. H.: Brain Stem Evoked Responses Associated with Low-Intensity Pulsed UHF Energy. Jnl. App. Physiol. 23, 984 (1967).

32. Tanner, J. A., Romero-Sierra, C. and Davie, S. J.: Non-Thermal Effects of Microwave Radiation on Birds. Nature 215, 1139 (1967).

33. Korbel, S. and Thompson, W. D.: Behavioral Effects of Stimulation by UHF Radio Fields. Psych. Rep. 17, 595 (1965).

34. Wei, L. Y.: Role of Surface Dipoles on Axon Membrane. Science 163, 280 (1969).

*35. Michaelson, S. M.: Soviet Views on the Biologic Effects of Microwaves. 21st Amer. Cong. Expt. Med. Biol. 52A9 (1968).

36. Cleary, S. F. and Pasternack, B. S.: Lenticular Changes in Microwave Workers. Arch. Environ. Health. 12, 23 (1966).

37. Cleary, S. F., Pasternack, B. S. and Beebe, G. W.: Cataract Incidence in Radar Workers. Arch. Environ. Health 11, 179 (1965).

*These references were included in the basic reading list of microwave-biological effects previously supplied to the Task Force.