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MR 488

BIOLOGIC EFFECTS OF RADIO AND MICROWAVES: PRESENT KNOWLEDGE; FUTURE DIRECTIONS

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Historical Background

Man's need for communication has led him to investigate electromagnetic energy, and to develop it to suit his needs. Initially he was forced to rely on a solid physical conduit to transmit this energy; at the turn of the century, Marconi changed all the rules. Since that time man has looked on the electromagnetic spectrum and appropriated ever larger portions of it for his use. With increasing knowledge he has been able to propagate energy at higher and higher powers over greater and greater distances using more and more of the spectrum - and he has seen that such growth has brought with it the real possibilities of biologic penalties.

The medical community did not wait for the development of communications equipment to discover the effects of certain radiofrequencies. As early as 1890, d'Arsonval demonstrated that electric currents at frequencies of 10 kilohertz caused heating of tissue. By 1900, currents at frequencies of 1-3 megahertz were being used for diathermy. In the thirties, Burr and his associates, and Northrop began to discover other effects of electromagnetic fields on biologic systems.

In the late thirties, the idea that radio waves could be used not only for the dissemination, but also for the creation, of information became established. Radar was born just in time to play a vital role in a great war. Power levels increased, and definite perils appeared. At first the physiologic effects were suspected but dismissed; later they were proven and used in changing man's physiology for the better; still later their dangers became evident. At this point man began to try to quantitate the effects which he saw.

Increasing power levels and power densities have become the rule of the day. Mumford has stated that man's ability to generate microwave power has been increasing at the rate of 15 db per decade. In 1955 the military became increasingly aware of the hazards and accepted the responsibility for research in this area since at that time it was the largest single user of radar equipment. The School of Aviation Medicine started a 2 1/2 year effort in the field. In 1956 a tri-service panel was established by which it was determined that the Air Force should have research responsibility in the field of microwaves. A research program was established and annual tri-service conferences were held, the first in 1957 and the last in 1960. At the time of the last conference the late Dr. - then Colonel - George M. Knauf made the statement that "we have not seen any research data which shake our faith in the validity of this arbitrary safe level (i.e., 10 mw/cm^2) which we sponsored some five years ago."

Since that time research has continued with decreasing levels of effort. The Aerospace Medical Division sponsored the research performed by Dr. Michaelson and his group at the University of Rochester. This work, started on 1 March 1958, was not funded beyond FY67. The final report from this project was published in November 1967.

Radiations Under Consideration

Traditionally, the term microwaves has been applied to that portion of the spectrum lying within 300 megahertz and 300 gigahertz. Most of the sparse knowledge which we now have is concentrated within this range. At frequencies higher than this, approaching the infrared portion of the spectrum, the penetrability of the energy becomes very low, so that effects are almost exclusively limited to the skin, and are thermal in nature.

However, advancing technologies have again extended our interests in the other direction, so that radiowaves in the HF and VHF areas, from 3 to 300 megahertz, are coming into use in radar technology. We must be alert to the possibilities of physiologic change at these frequencies, particularly in view of the power levels which may be in use. While we have used the term microwave to describe the former group of frequencies, my colleagues in the USAF School of Aerospace Medicine have proposed, a la mode, that the lower frequencies be described as miniwaves.

Perhaps it is fortunate that our research is not going in the other direction.

Biologic Effects

Research into the effects of microwave radiation has been a matter of continuing interest. An early report by Daily in 1943 looking at the effects of microwaves during World War II came to the conclusion that, while the hazards were indeed potential, they were not measurable. In all likelihood this was occasioned by the low power levels which were in use at that time. One of the first experiences reporting hazards from microwaves was noted by Hirsch of the Sandia Corporation in 1951. At that time a young technician reported to him because of a 10-day experience of fuzzy vision with no prior complaint. The circumstances were that for one year the technician had been visually examining the radiating area of a microwave antenna while power was being applied. Hirsch diagnosed bilateral cataracts with acute chorioretinitis. The frequencies at interest were between 1.6 and 3.3 gigahertz with the power level calculated to be in the order of 100 mw/cm^2. This prompted a widespread interest in the potential effects of microwaves and spawned investigation into several other possible clinical effects. It might be noted at this time, however, that one report of tissue destruction and death from microwave radiation submitted for publication in September 1956 presented a highly suspect case. While the author attributed death to exposure to microwave radiation directly in the primary beam and within 10 feet of a radiating antenna without further definition of the power output, frequency, or repetition rate, a further review of the case by other parties has led to the conclusion that this death was in fact due to acute appendicitis unrelated to a microwave exposure.

Essentially the effects of microwaves may be divided into two groups: thermal effects and nonthermal or athermal effects.

Thermal Effects

Thermal effects from microwaves occur as a direct result of tissue heating. As a dependent of frequency, tissue heating may occur at any point between the skin of the subject in the case of frequencies in the order of 10's and 100's of gigahertz to deep tissue heating at lower frequencies. The susceptibility of the body to effects of such heating is largely a function of the body's ability to dissipate heat. One of the most effective methods of heat dissipation is occasioned by blood circulation which picks up heat at the site of its production and by appropriate vascular changes delivers the heat to the point at which it can be reradiated. Thus deep tissue heating may be relieved to some extent by the dilatation of the arteries serving the involved areas and the further dilatation of a subcutaneous capillary bed where the heat may be radiated to the atmosphere. It follows from this that the areas in which vascularization is the poorest are potentially the most susceptible to microwave damage. This is born out by the fact that in the human, with one possible exception, the critical organ for microwave damage appears to be the crystalline lens of the eye. This structure is essentially avascular and thus cannot dissipate heat deposited therein. Changes occur first in the subcapsular area at the posterior pole of the lens and later extend in the fashion typical of cataract maturing. It has been calculated independently of the work of Hirsch cited above that the threshold for change is most likely at power levels around 120 mw/cm^2. Once the initial change has been triggered cataract formation will proceed without further exposure to the harmful agent. Thus, it is conceivable that a cataract may first become recognized several years after exposure to microwaves has been terminated.

The possible exception to this rule of critical organs involves the testes. Based on the juxtaposition of two observations it has been postulated that levels in the order of 5 mw/cm^2 can cause testicular damage. One observation is the fact that undescended testes kept at normal body temperature of 98.6^o are almost invariably sterile. Normal testicular temperature is considerably below this because of the large radiating surface within which they are inclosed. Additionally, power levels of 5 mw/cm^2 are sufficient to raise a dog's testes to this temperature level and to maintain them at this level. These facts were wed to speculate a hazard level of 5 mw/cm^2 for the testes by Eli in 1959. As contrasted with the eye, however, changes here are easily reversible and permanent damage is most unlikely. Many cases have been reported in the literature purporting to show a sterilizing effect of microwave radiation, the most recent of which occurred in the Journal of the American Medical Association in July 1968. Published over my strenuous objections, this paper reported a case of hypogonadism and possible sterility of a radar technician who had been exposed to microwave radiation of undisclosed parameters. The presence of a 4-year old daughter in the family was used to establish his previous fertility.

Turning to thermal effects on the whole body we find that the work of Michaelson and his associates at the University of Rochester demonstrated a threshold value for thermal stress of about 100 mw/cm^2 at frequencies of 1240 megahertz and 2800 megahertz. At this level dogs could cope with the stress for up to six hours. However, when the field was increased to 165 mw/cm^2 thermal accommodation was no longer possible and breakdown occurred at the end of about five hours. The thermal effects could be modified in several manners. The lower the ambient temperature and humidity the more resistant the dogs were to thermal stress. Certain drugs given prior to exposure altered the response to microwave radiation. Anesthesia induced by pentobarbital, and sedation under the influence of chlorpromazine and morphine sulphate caused the rectal temperature to rise more rapidly than in dogs not previously medicated. In those not carried to termination the period of cooling following exposure was likewise prolonged. However, certain other drugs appears to cause an increased resistance to microwaves making the animals more tolerant. It has been postulated that these drugs caused an initial drop in temperature and thus altered susceptibility.

Of all the members of the animal kingdom man enjoys the reputation of having the best thermal regulation. Ely and his associates have estimated that man is capable of dissipating 1 kilowatt of absorbed power, somewhat less than that incident on him lying prone in the noonday sun at the equator. Thus, the figures which we cite for thermal regulation as studied in the dog carry with them, when they are extrapolated to man, a factor of safety.

There are other thermal effects which occur. Hematologically, lymphocyte and eosinophil depression occur. These effects were barely recognizable at a level of 20 mw/cm^2 for 1280 megahertz waves. They become better defined at 50 mw/cm^2 and definite at 100 mw/cm^2. Hemo-concentration occurs, probably associated with loss of body fluids with temperature elevation. Apparently in response to repeated such exposure lymphocytosis eventually occurs, the hemoconcentration decreases, and reticulocytes increase. Some of these effects exist over long periods of time. These include increased fragility of red cells which may be noted 12 months after a single 1280 megahertz exposure to 100 mw/cm^2 for six hours. There is a possibility that changes in the vascular system resulting from microwave exposures may under certain circumstances cause deleterious changes in the vascular flow to the heart. Central nervous systems changes are evident in that animals exposed at unspecified levels showed impaired locomotion. Bathing the head alone in a field of 2800 megahertz at 165 mw/cm^2 resulted in more rapid temperature changes than were noted in whole body exposure. Endocrine changes occurred in certain exposed animals.

Studies of the thyroid showed the gland accepted more ^{131}I and thus was more active following exposure to microwaves than in normal animals. This persisted for as long as three years following a single exposure to 1280 megahertz waves at 100 mw/cm^2 for six hours. As might be expected in fields of high intensity local tissue changes occurred including the production of burns, particularly over the rib cage, which were remarkably slow in healing.

It will be noted from this description of microwave effects that such changes have been seen at levels as low as 20 mw/cm^2. This has caused all of us to view with an increasingly skeptical eye any efforts to raise present exposure limits.

Nonthermal Effects

When we consider the nonthermal effects of microwave radiation we approach an area which is much less clearly defined.

Much of the work in this area has been done by the Russians. The first paper in this field that has come to my attention was published by Tonkikh of Leningrad in 1941. Several publications have reviewed their level of activity and the implications of their research. In the most recent evaluation, 194 names of workers actively engaged in the field were reported. Additionally, twenty institutions were listed where medical microwave research is in progress. This indicates unusually high interest and priority of work in this field.

While the Russian researchers agree to the importance of thermal effects, they feel that the nonthermal effects are equally important. While one author describes the varying changes which are seen at low levels as being nonthermal, this is not universally accepted in that some feel that these effects are indeed thermal but at the cellular level. They have been most vocal in expressing their opinion that nonthermal or athermal effects occur at much lower exposure levels and thus become the limiting factor in setting exposure guides.

Most such workers consider the nonthermal effects to be mediated primarily by the central nervous system. One research effort described a large group of workers in the field of microwaves. They divided the group into four sub-groups on the basis of total time in the job ranging from 0 to 3,000 plus hours. In these workers they described an asthenic syndrome of varying severity, cardiovascular disorders including pulse and pressure lability, alteration in acid formation in the stomach, alteration in glycogenesis in the liver, and a labile leukocyte count. One of their better research efforts describes the production of electroencephalographic changes in the brain of a rabbit at levels of about 5 mw/cm^2. These changes were well documented and were definite.

The fact that most of the Russian work in this field is Pavlovian in nature tends to bring its credence into question. For instance, one report uses terms to describe shifts in reflex activity such as "disinhibition and depression of reflex activity" both as a result of exposure to microwaves.

In this country a fair amount of work has been done on the nonthermal effects. Primary in this field has been Frey. In 1961 and in subsequent years he has described the presence of an auditory response to microwaves in the range of 200 to 3,000 megahertz. This response has been detected at levels as low as 400 uw/cm^2. It has been seen, however, only in pulsed generators. The rep rate varied between 244 and 400 pulses per second. These responses were noted when the head itself was irradiated and were blocked when the head was shielded. It is very likely, however, that this is a function of the rep rate of the microwave carrier wave and not a function of the presence of microwaves per se. While not very flattering, it is very possible that the skull acts as a resonating chamber. He has also described the presence of paresthesias, or numbness and tingling, in the presence of high energy microwave fields. This would appear to be a direct microwave effect. Of more interest has been work of his presented in 1967 in which he describes brain stem responses associated with low intensity pulsed microwave energies. These responses have been noted in the 1.2 to 1.5 gigahertz region at levels of 30 uw/cm^2. Their presence has been demonstrated in the instrumented cat. Other interesting phenomena are worthy of comment. The Navy has realized for a long time that carrier deck crewmen who are exposed to relatively high intensity microwave fields during their watch show at the completion of this time symptoms such as hyperirritability, fatigue, and lassitude which, while they may be a function of the high degree of tension under which they are working, may not be entirely explained in this manner. It has been noted that certain laboratory workers who have been investigating effects of microwaves have shown neuro or neuropsychiatric changes which seem to be significant.

While large numbers of Russian workers are involved in the field of microwave research it is interesting to note that a group of Russian workers who had been prominant in the field has recently been organized into a group to study parapsychic phenomena. Included in this group are some of the leading workers in this field, such as A. S. Presman. There are representatives of the fields of radio engineering, technology, hypnosis, medicine, biology, and physiology.

Exposure Standards

Based on all the work cited above, maximum permissible exposure levels, referred to as MPEL, have been under continuous consideration since about 1953. While it is now customary to refer to such levels as those at or below which there is assurance that no change will occur, this has not always been the case in considering hazards for microwaves. Early standards were variously based on levels below which no changes were noted, called safe levels, and levels at or above which definite changes were known to occur, referred to as hazard levels.

The work of Hirsch, in which he stated that cataracts may occur at levels of 100 mw/cm^2, was initially used as a point of reference. One of the first levels to be adopted was that of the Navy in April 1953. It was agreed that 100 mw/cm^2 would be described as a damage risk criterion. In November 1953, on the other hand, the Central Safety Committee of the Bell Telephone Laboratories established a safe level of 0.1 mw/cm^2. In June 1954, General Electric listed 1 mw/cm^2 as a safe level. In about 1955 the Air Force, which had initially embraced the Navy's hazard level, reduced their MPEL to 10 mw/cm^2 and considered this to be a safe level. This was formalized in 1957 but was still not thoroughly accepted in that Schwan and his group felt that it should not apply for whole body absorption for more than one hour.

With the Air Force's establishment of a safe level of 10 mw/cm^2 industry felt that, since the Air Force was the largest single generator of microwaves, its estimate of safe level should be considered. At that time the Bell Laboratories raised their level to 1 mw/cm^2 agreeing with General Electric. Subsequently, in 1958 they adopted the Air Force standard, but referred to it as a hazard level. General Electric followed suit one year later. The Navy and the Army made the Air Force's position a tri-service one in 1958 adopting the 10 mw level for the entire microwave spectrum. This standard has remained in effect in this country since that time. In 1966, under the co-sponsorship of the IEEE and the U.S. Navy, the U.S.A. Standards Institute recommended as a radiation protection guide for frequencies from 10 megahertz to 100 gigahertz, an MPEL of 10 mw/cm^2. All of the standards have been based on the presence of thermal effects.

There has been some question as to the appropriateness of a time factor in such standards. A time factor does indeed exist - infinity. Thus, the levels state that one may be exposed at these frequencies and power densities for an indefinite period of time. The Air Force, recognizing the need for maintenance in high intensity radiation fields, has adopted an additional exposure standard which states that one may be exposed in a field as high as 100 mw/cm^2 for a period of time as a function of the power density expressed in the following empirical formula: $T_e = \frac{6000}{P^2}$, in which T_e = permissible exposure time in minutes, and P = power density in mw/cm^2. Because exposure times of less than two minutes are hard to control, in effect this standard prohibits exposure in fields of greater than 57 mw/cm^2.

The Russian bloc has taken an entirely different tack in this subject. Since they feel that nonthermal effects are equally as important as thermal effects their standards are based on the former. They establish three criteria, one for the individual exposed during a continuous working day, one for those exposed for approximately two hours per day, and one for those exposed for 15 to 20 minutes. These levels adopted in 1956 are 10 uw, 100 uw, and 1 mw, per cm^2 respectively. The second and third groups must wear protective equipment. While it was initially felt by many responsible authors in this country that such levels, quite difficult to measure and to enforce, were established primarily to embarrass this country's operational capabilities, it has become the feeling now that their levels are based on a genuine appreciation of what they feel to be hazardous conditions. This re-enforces the need for us to re-evaluate our standard.

Areas of Uncertainty

I have previously listed much of the current knowledge in the field of microwave effects. This knowledge, while in certain areas is fairly deep and complete, in other areas is quite inadequate. In the area of thermal effects of microwaves much attention needs to be paid to the difference in effects between continuous wave microwave energy and such energy propogated in a pulsed mode. There is certain evidence to lead us to believe that the effects from pulsed microwaves may appear at lower levels or be more severe.

In the area of nonthermal effects very little effort has been made to reproduce the voluminous Russian work. The fact that possible hazards do exist in the nonthermal area leads us to question the applicability of the 10 milliwatt rule. If indeed nonthermal effects appear at levels considerably below this our entire program must be revised. However, if we can institute a thorough evaluation of such nonthermal effects and can disprove either their existence or their importance we may be able to substantiate the validity of our current levels.

Almost all of the work in the area of microwave effects has been done in the frequencies in excess of 200 megahertz. The area below this is becoming of increasing concern to us with the development of techniques which will call for the propagetion of high intensity beams in these frequencies. While the rule of thumb states that for significant biologic effects to occur the size of the body being affected must be equal to or greater than 1/10 of a wave length of the radiation in question and thus removes from biologic consideration those frequencies below 15 megahertz, this rule has never adequately been proved. Too, there is evidence to lend credence to the possibility of biological effects occurring at discrete frequencies, perhaps as a result of generation of harmonics or resonance frequencies. Thus the possibility may exist for a biological effect to occur at, for example, 18 megahertz with no effect at either 17 or 19 megahertz. Again, careful investigation must be conducted to illuminate this point.

Other new technologies call for the generation of extremely high power levels in single pulses - power levels which may reach 16 Kw/cm^2. While our exposure guides call for averaging of power over time no account is taken of such single high energy pulses. To my knowledge no studies have been made of the biological effects of such pulses.

One of the most glaring deficiencies is the lack of suitable instrumentation. This need cuts across the board ranging from the need for a simple omnidirectional frequency independent measuring device capable of being utilized in the field to a similar device with more sophistication capable of being utilized in the laboratory. It is an unfortunate characteristic of most instrumentation currently available that the mere presence of the instrument in the microwave field creates a sufficient perturbation of the field so as to render the reading questionable if not meaningless. Such instrumentation is also highly sensitive to the presence of other objects in the microwave field. In order for any laboratory work to be meaningful such instrumentation must be available. In order to provide the field user the benefits of the laboratory investigations such an instrument for field use must also be available. We are currently actively engaged with the National Bureau of Standards in the pursuit of this question.

Future Research Needs

The need for future research efforts in the area of microwaves is pressing in point of view both of its timeliness and of the huge amount of lack of knowledge which confronts us. To answer the problem of effects in the HF area, I feel that investigations should be made to delineate any changes resulting from such radiation and to quantitate the changes seen. Should research along these lines provide new clues into either specific thermal or nonspecific nonthermal effects further avenues of research will be opened. Of particular interest to me is the possibility of chronic low dose exposure over a long period of time in which a trained animal will be observed for a capability to maintain performance in one or more of several categories. This may throw some light not only on the nonthermal effects as they may affect the animal's performance, but also on the general effects, be they thermal or nonthermal, such as those which I have listed. I would anticipate that eye effects will probably predominate but I would like to investigate other such parameters as hematologic, endocrine, and biochemical changes. Concomitantly there is a need to develop the instrumentation to which I have referred.

Our predecessors have provided us with a large basis of knowledge on which to build. Some of the questions which they have faced they have answered forthrightly and to the satisfaction of all of us. In other areas they have provided us with information which is tantalizing in its ramifications and whose validity has yet to be established. The field is wide and the opportunities are great.

The views expressed herein are those of the author and do not necessarily reflect the views of the U.S. Air Force or the Department of Defense.