Session F. Presentation and Discussion of Session Reports, Conclusions (Including Future Research Needs) and Recommendations

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MICROWAVES — A TOOL IN MEDICAL AND BIOLOGIC RESEARCH

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INTRODUCTION

When microwaves are incident on a medium a certain proportion of the incident energy will be reflected and the rest transmitted through the interface into the medium. This transmitted energy will be partly absorbed and the remainder will emerge from the medium without any interaction having taken place. For this latter radiation the medium is behaving as a transparent object. This simple picture is, of course, obvious but it does enable the problem of the degree of interaction of microwaves with biologic tissue to be broken down into two parts: For a microwave of a given frequency how much energy is reflected and how much energy is absorbed? These questions can, in principle, be answered if the angle of incidence and the complex permittivity of the tissue are known. In practice the former quantity is only known under well controlled experimental circumstances, e.g. if the tissue is contained within a waveguide or coaxial line, or for certain well defined free-space conditions. The complex permittivity of biologic materials can, however, be rigorously determined for a given sample and provided the sample can be taken as typical for the form of tissue which it represents, it should be possible in principle to build up a collection of data for the electrical properties of body tissues. There is one important property which most biologic materials possess and which enables this hope to be partially realised in practice. Most tissues have a high aqueous content and in the microwave frequency

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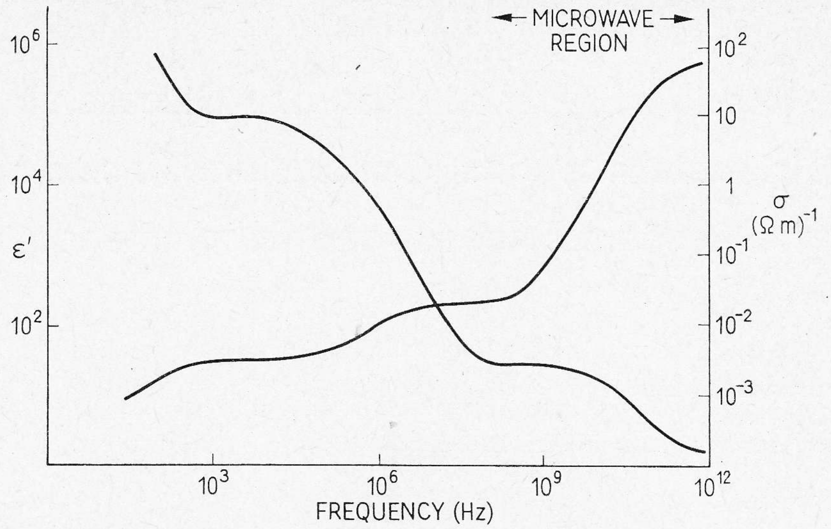

Fig. 1. Fall of permittivity (ε′) and increase in conductivity (τ) with increasing frequency for a typical biologic tissue (the profile of the curve for the attenuation coefficient is similar to that for σ).

region (300 Mz—300 GHz) the electrical properties of water dominate those of all the other biologic molecules present. At lower frequencies this would not be the case: for example the electrical permittivity of blood at frequencies of a few kHz is equal to several thousand whereas at 3 GHz it is around 60. This situation is further illustrated in Figure 1 where it is seen that in the microwave region the electrical conductivity of a biologic solution increases by a factor of around 10^4 while the permittivity decreases by a factor of about 15. These changes are due almost entirely to the water content, and constitute the γ-dispersion. The β-dispersion is due to the biologic macromolecules and the δ-dispersion is usually regarded as being due to the bound water (11) or to the side-chains associated with the macromolecules or to a combination of both effects (19).

Thus if we know the dielectric properties of water between 300 MHz and 300 GHz we are able to predict roughly how a given biologic tissue will behave when subjected to microwaves of a specified frequency. According to this picture if the volume of a biological solution consists x% of macromolecules (e.g. nucleic acids or proteins) and (1—x)% of water then the values of the electrical parameters of the solution at a given frequency and temperature will be about (1—x)% of the values for the same parameters of water at the same frequency and temperature.

This approach, although giving a useful overall picture, can be criticized on several counts. It is known that the structure of the water immediately surrounding the biologic macromolecules in solution is different from that occurring in pure water, and there is good reason to think that the electrical properties of this "bound" or "modified" water may be different from those of pure water at the same frequency. Another consideration is the possibility of resonance absorption, which can be defined as selective absorption of energy in a narrow frequency band. The bound water phenomenon is well established and there is some evidence (20), (4) that resonance absorption could occur; both of these topics will be considered later in the paper. It can be stated at this stage, however, that for a proper understanding of the mechanism of absorption

WHO – BIOLOGIC EFFECTS & HEALTH HAZARDS OF MICROWAVE RADIATION 1974 of microwaves in biologic material it is necessary to know the electrical permittivity and conductivity as a continuous function of frequency over as large a part as possible of the frequency region 300 MHz—300 GHz and at a temperature of 36.9°C. Moreover, it is not only the calculation of microwave absorption and the subsequent evaluation of microwave hazards which require the knowledge of these electrical parameters. They may be used in other areas of medical and biologic research, such as the investigation of the molecular aspects of hyperbetalipoproteinemia, the treatment of malignant disease by hyperthermia and the evaluation of the size and shape of biologic molecules in an aqueous environment. These and other aspects will be discussed later in the paper.

ELEMENTARY THEORY AND EXPERIMENTAL METHODS

The complex relative permittivity of a material may be defined by the expression

$$\hat{\varepsilon} = \varepsilon' - j\varepsilon'' \quad [1]$$

where ε', the real part, is traditionally referred to as the dielectric constant while ε'', the imaginary part, is the dielectric loss factor. When an electromagnetic wave traverses a medium ε'' is a measure of the energy absorbed per cycle by the medium. Since the length of the cycles gets shorter as the frequency increases ε'' will eventually decrease to zero although the total energy absorbed by the medium is finite. Hence ε'' is not a realistic parameter for assessing energy absorption. A better parameter to use would be the conductivity $\sigma = \varepsilon''/\omega\varepsilon_0$ where ω is the angular frequency of the radiation and ε_0 is the permittivity of free space. It is well known from simple electromagnetic theory that the energy absorbed by unit volume of a medium in unit time is related $\sigma E'$ where E is the strength of the electric field. Even this expression is not applicable to a microwave passing through an absorbing medium such as a biological tissue, however. This is because the field strength is not constant throughout the medium but diminishes due to attenuation. Thus if a microwave with an electric field strength E_1 is attenuated from E_1 to E_2 by a width x of tissue then $E_2 = E_1 \exp(-\alpha x)$ where α is the attenuation coefficient of the medium at that particular frequency. Hence the energy absorbed is proportional to $| -\exp(-2\alpha x)$. The relationship between α and the complex permittivity for a TEM mode is given by

$$\alpha = \frac{2\pi f}{c}\left[\frac{(\varepsilon'^2 + \varepsilon''^2)^{\frac{1}{2}} - \varepsilon'}{2}\right]^{\frac{1}{2}} \quad [2]$$

where S is the microwave frequency and C is the velocity of electromagnetic radiation *in vacuo*. This makes the relationship between absorbed energy, the frequency and complex permittivity a fairly complicated one. When α is small, however, $| -\exp(-2\alpha x)$ tends to $2\alpha x$ which when combined with suitable approximations to equation [2] shows that the absorbed energy is proportional to α in this limiting situation, or to σ. This corresponds to the low-frequency end of the dispersion region and therefore approximates to the well known case of a medium between the plates of a condenser where simple theory indicates that absorbed energy is proportional to conductivity. In general, however, it must be emphasized that the parameter determining energy absorption is the attenuation coefficient α. The variation of α with frequency is a similarly shaped curve to the corresponding variation for conductivity shown in Fig. 1 in that it starts at a low value and attains a plateau at the high-frequency side of the dispersion region.

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The relationship between the energy reflected from the interface of the medium and the dielectric parameters is also complicated but to a first approximation is proportional to

$$\left[(\varepsilon')^{\frac{1}{2}}-1\right]^{2}\left[(\varepsilon')^{\frac{1}{2}}+1\right]^{-2} \qquad [3]$$

if the wave is incident from air. Thus in view of the rapid changes of the complex permittivity throughout the microwave region for a biologic material, the importance of knowing ε' and ε'' (and hence α) accurately at each frequency of interest is seen.

Techniques for measuring $\varepsilon = \varepsilon' - j\varepsilon''$ for lossy liquids at microwave frequencies fall into three main categories. These are resonance methods, standing wave methods and traveling wave methods. Resonance methods have been used by Schwan (22) to measure the permittivity of a wide range of biologic solutions (23) at frequencies up to 1 GHz. At higher frequencies the increasing conductivity (Fig. 1) causes a rise in the energy absorption and the resonance type of method becomes less sensitive although methods have been used recently at 2.6 GHz using waveguide cavity resonators (e.g. Masszi (17) and Almassy (2)). Techniques using a movable probe in a coaxial line have been employed by Buchanan and Grant (5) and have been subsequently developed by Pennock & Schwan (19) by Grant and Keefe (10) by Jordan (16) and by Sheppard (25), (26). These have worked satisfactorily from 300 MHz up to 4 GHz and are currently being extended to 8 GHz. At higher frequencies the waveguide bridge method as described by Buchanan (3) or by Grant and Shack (12) must be used.

RESULTS

We have been studying the electrical behavior of biologic solutions for the past twenty years at the Middlesex Hospital Medical School, Guy's Hospital Medical School and during the last seven years at Queen Elizabeth College, London. Some of this work has been carried out in collaboration with other centers; in particular with Portsmouth Polytechnic, the Department of Biomedical Electronic Engineering at the University of Pennsylvania, the Courtauld Institute of Biochemistry and the MRC Clinical Genetics Unit at the Institute of Child Health, London and with the Simon Stevin Institute at Bruges, Belgium. Substances measured include aqueous solutions of hemoglobin (15), myoglobin (27), ribonuclease and serum albumin (9), whole blood, lipoproteins (14), smaller biologic molecules typified by various amino acids (23) and peptides (1), and water itself (13). The results have been described in various publications, some of the principal ones being listed at the end of this paper. To cover the three principal dispersions (Fig. 1) measurements have been made from a few kHz up to 35 GHz. Since, however, this Conference is only concerned with the frequency region 300 MHz — 3000 GHz the β-dispersion is not relevant. One recent study has been concerned with the permittivity of whole blood at 2 GHz for various concentrations of hemoglobin. In another experiment the dielectric properties of solutions of LDL lipoproteins taken respectively from normals and from patients with hyperbetalipoproteinemia have been measured at 800 MHz and significant differences found (14). In a third study the dielectric behavior of water has been measured between 400 MHz and 4 GHz (13).

The results of the first two studies will now be described briefly. Blood is composed of living cells and plasma, a heterogeneous mixture of molecules of which the majority are polar. The dielectric behavior of blood has been studied previously by Schwan

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(21) and Cook (7) and as a result of this work it is known that the dielectric constant falls from a few thousand at radio frequencies to about 60 at about 300 MHz from which it then falls through the microwave region to a value of between 4 and 5 at 300 GHz. This variation follows the typical pattern shown in Figure 1. The high value of E′ at low frequencies is due to the red cell membrane and the rotation of polar macromolecules. In the microwave region the permittivity is, as expected, due mainly to the free water molecules. Hence any variation in ε′ due to changes in the concentration of red cells or serum proteins should be due solely to changes in the relative proportion of the volume occupied by free water. We have tested this hypothesis by measuring the permittivity at 2 GHz of blood of different hemoglobin concentrations. Five samples were measured of hemoglobin concentration (c): zero (pure serum), 4.1, 6.8, 9.1 and 15.0 mg/ml, the final concentration corresponding to blood from a healthy person. The values of ε′ at 2 GHz and 23.6°c were 70.0, 66.4, 64.3, 62.6 and 58.0 respectively. This result shows a linear relationship between ε′ and C and proves that, at microwave frequencies, the contribution of the hemoglobin to the permittivity is small and is negative, i.e. it has its effect by displacing free water molecules. The proportionality between permittivity and hemoglobin concentration is interesting and could form the basis of an alternative method of measuring hemoglobin concentration.

The second application of dielectric methods is in the field of lipoproteins. There is a strong association between the incidence of coronary heart disease and the concentration of cholesterol in the serum. Furthermore, for cholesterol concentrations greater than 325 mg/100 ml the risk of dying from coronary heart disease is ten times greater if the hypercholesterolemia is caused by the mutant gene for familial hyperbetalipoproteinemia. It would therefore be very useful if the genetically determined form of the disease could be distinguished from that which is due to environmental causes. We have measured the dielectric constant (ε′) of aqueous solutions of low-density lipoproteins of density range 1.007—1.063 g/ml (LDL). The measurements were carried out at 800 MHz in a coaxial line and at 20°C. Blood samples were obtained by venepuncture from three normals (N), two heterozygotes (He) and one homozygote (Ho). The mean values of permittivity were 72.77 ± 0.17, 72.36 ± 0.14 and 72.01 ± 0.19 for N, He and Ho respectively at a concentration of 61.0 mg/ml of lipoprotein in water. These were interpreted by a simple mixture formula in terms of the hydration (bound water) to give the hydration ranges of 0.00—0.06, 0.07—0.11, 0.11—0.17 g lipoprotein/g water for N, He and Ho respectively. The ranges correspond to the 95% confidence interval. Thus the results of this pilot study (14) show significant differences in the hydration (w) between the normals and both types of familial hyperbetalipoproteinemia. This work is now being extended to include larger numbers of subjects in each category.

The values of w for the lipoprotein are much smaller than those obtained for globular proteins but this could partly be attributed to the fact that a given macromolecule might be expected to bind a certain layer of water rather than a certain mass. In this case the hydration factors would tend to be larger for the smaller molecules and vice versa.

DISCUSSIONS AND CONCLUSIONS

It has been assumed for some considerable time that the degree of reflection and absorption of microwaves by a biologic tissue is mainly determined by the value of the complex permittivity of water at the frequency in question. In my view some

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important practical and clinical implications are going to be missed if this simple picture is accepted without reservations.

In the second example cited in the previous section the dielectric behavior of the bound water is seen to be quite different from that of the free water. There is still a great deal to be discussed about the dielectric behavior of protein-bound water but most workers (11, 19, 28) agree that its relaxation frequency lies between 100 MHz and 1 GHz. The static (ε_s) and infinite frequency (ε_∞) permittivities of bound water are not yet known with much precision but since for ice ε_s is only a few percent higher than ε_s for free water the value for bound water is unlikely to be very different. The same goes for ε_∞. These facts can now be applied to a situation of practical interest.

At the temperature of the human body the relaxation frequency of pure water is 26 GHz which is therefore about ten times greater than the operating frequency of a microwave oven which, in turn, could be about ten times greater than the relaxation frequency of bound water. Assuming this to be so and assuming that ($\varepsilon_s - \varepsilon_\infty$) is the same for free and bound water it can be calculated from equation (2) that the attenuation coefficient (α) of bound water at 2.45 GHz is about three times as high as that of free water. Since it is α that determines the energy absorption and since, also, the bound water molecules are immediately adjacent to the biologic molecule being damaged the importance of knowing the dielectric parameters of the bound water as well as the free water is abundantly clear.

The possible role of bound water in relation to genetically induced hyperbetalipoproteinemia has been explained above. Another area of clinical interest is the treatment of cancer by hyperthermia. It has been shown by Cavaliere (6) and others that malignant cells are more susceptible than normal cells to damage from thermal stimuli. Temperatures of between 41.5°C and 43.5°C are usually involved in these studies. Recently Overgaard and Overgaard (18) have used electromagnetic waves of 27.12 MHz to treat mammary carcinoma in mice by hyperthermic action and, on the more fundamental side, Drost Hansen (8) has suggested that the effectiveness of hyperthermia therapy may be due to structural transitions in the water associated with the cells at 45°C. The exact mechanism of action may turn out to be complicated but it is a reasonable hypothesis that water, probably in both free and bound forms, is involved at some stage of the process. In that case it would be far more effective to use microwaves, rather than radiation with a frequency of a few tens of MHz. It would be well worth while investigating both the optimum frequency and the mechanism of action of electromagnetic waves when used for the treatment of malignant disease by hyperthermia.

Another phenomenon of great importance in the absorption of microwaves by biological tissue is that of resonance absorption. If it exists it could have significant repercussions as regards microwave radiation hazards. In resonance absorption a sharp peak in the attenuation coefficient occurs over a small frequency range and the presence of this peak would be unobservable outside the range. I am not aware that resonance absorption has been observed in biologic material but evidence has been advanced by Roberts and Cook (20) and by Buchanan (4) for its existence near 6 GHz in some liquid methyl esters. In view of the connection between energy absorbed and attenuation coefficient it would be satisfying to be able to preclude the existence of resonance absorption in biologic tissue over the microwave range of frequencies.

The conclusions and suggestions for future work may be summarized as follows:

(a) Although the overal dielectric behavior of biologic material at microwave frequencies is mainly determined by its aqueous content the effect of the bound water must be considered when evaluating thermal damage to the biologic macromolecules present. In general the dielectric parameters of bound water at microwave frequencies will be different from those of free water and the attenuation coefficient of the former

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may be higher than the latter at some frequencies. Owing to the association between energy absorption and attenuation coefficient, and to the close proximity of bound water to proteins and other macromolecules, the effect of the bound water may be crucial as regards microwave radiation hazards.

(b) In addition to their heating effect in tissues microwaves interact with the electric dipole moment of biologic molecules. These interactions may be observed and interpreted in terms of the shape and size of the macromolecules and the nature of the structure of the water in the neighboring environment. Such parameters may be correlated with the incidence and treatment of certain diseases with which the molecules in question are associated. In this way it would be possible to find a direct link between a clinical condition and a structural abnormality at a molecular level as, for example, has been done in the case of sickle-cell anemia and hemoglobin.

(c) Information about the parameters referred to in (a) and (b) can be obtained by determining the complex permittivity of the appropriate biologic material over a wide frequency and temperature range.

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SUMMARIES OF DISCUSSIONS, SESSION REPORTS AND RECOMMENDATIONS

SESSION A. GENERAL EFFECTS OF MICROWAVE RADIATION

Z. V. Gordon, T. V. Kalada. M. L. Shore and H. P. Schwan

Following Dr. Michaelson's paper a question was raised relative to the problem of extrapolation of experimental results to man. The author indicated in his reply that in attempting to make such extrapolations it is important to take into consideration all of the known attributes, similarities and differences between animals in order to develop extrapolation factors. Possibly the basal metabolic rate could be used as one of these. The question of comparability of results obtained on different animal species recurred later in the general discussion. It was felt that a sort of sliding scale based on physical (exposure conditions, the geometry of the animal relative to wavelength etc) and physiologic species specific factors is needed.

Dr. Baillie was asked about absorbed power in the rats used in his study. In response he provided the following data: average weight 216 g, temperature rise 20°C, time 60 s, specific heat 0.83. Accordingly, the rate of energy dissipation was 0.25 kW or approximately 1160 W/kg.

The presentation by Dr. Gordon raised several questions: whether the described effects on erythrocytes are characterized by threshold values; can such effects be ascribed to thermal effects; and furthermore had physical or physico-mechanical models or concepts been developed to describe the interation between microwaves and cell membranes? It was made clear during the discussion that no threshold values could be determined as no systematic quantitative study at various intensity levels had been made; further experiments are needed to obtain an answer. However, at the levels used, thermal effects are improbable and it would be difficult to conceive thermal hemolysis under such conditions. Concerning the question of physical models or concepts, Dr. Schwan indicated that two possibilities exist: either weak effects can be explained on the basis of current concepts and existing data, or the very exciting possibility exists that entirely new principles of interaction are indicated that we have not yet been able to recognize.

In response to a question about the influence of modulation patterns of microwave fields on hypothalamic and other nervous system effects, Dr. Gordon indicated that the problem of modulation had not been investigated; it may, however, play a role.

Following Dr. Servantie's presentation there was a discussion of the possibility that drugs might modify the response of experimental animals to microwaves. Dr. Servantie noted that while this might be possible, in his experiments animals were irradiated before drugs were administered. Thus he did not feel that drug modification of microwave effects was a factor in his experiments.

Dr. Mikołajczyk pointed out the necessity for careful control of seasonal and diurnal variations in any type of endocrinologic experiment. Additional discussion followed a question on dose response. It was pointed out that the pituitary gland has an enormous reserve, perhaps amounting to 85 percent. Thus when endocrine shifts are noted it is difficult to tell whether they constitute a pathologic response. No possibility exists

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on the basis of the results of this investigation to establish dose-response relationships, in view of the endocrine reserve and the difficulty of defining pathologic changes.

Following the presentation by Dr. Nikonova a question was asked regarding other reports from the Soviet Union on effects of microwaves at low levels. Is it possible, that the effects attributed to microwaves could have resulted from exposure to X-rays or from a synergistic or additive effect of the two radiations rather than from exposure to microwaves alone? Dr. Nikonova indicated that while X-rays and microwaves do coexist in some occupational situations, when one speaks of low intensities both of microwaves and X-rays synergism is of little significance to the observed effect. Moreover the exposure to X-rays in the USSR is carefully controlled and at least in man in industrial conditions any effects of X-ray exposure seem highly improbable.

Following Dr. Czerski's presentation a suggestion was made that the effects he had observed were those that could be expected from thermal stress on cells induced by microwaves. In response, the author noted that the power densities used in this study were not associated with significant increases in body temperature. Dr. Schwan additionally indicated that the power levels employed by the investigator were too low to produce the effects observed on a thermal basis. He pointed out that levels at least 10 times greater than those used by Dr. Czerski would have to be employed to produce thermal stresses of the magnitude needed to produce the disturbances described in the paper. The author further noted that it would be difficult to explain experimental differences between pulsed and continuous wave exposure at the same average power density on a thermal basis.

Dr. Yagi was asked if he had observed superficial tissue burns, but replied that he had not. It was pointed out that this study was one that clearly involved significant heat stresses produced by high levels of microwave exposure.

After Dr. Rugh had concluded his presentation Dr. Gordon pointed out that Soviet investigators have observed similar effects to those observed by Dr. Rugh with 2—4 hour exposures daily during the entire period of gestation at levels of 6.5 mW/cm^2. Dr. Rugh pointed out that his study, using single acute exposures, measured integral absorbed dose. While the exact equivalence to plane wave fields was not possible, it was likely that the exposures in his study could have been higher than the dose indicated by Dr. Gordon by a factor of perhaps 15—20. This underlines the importance of studies on the effects of chronic exposures at low power intensities.

During the general discussion Drs Gordon and Schwan presented a proposal to distinguish three energy density flux levels of microwave fields. They suggested that microwave intensities be divided into the following three ranges:

(a) High intensities at which distinct thermal effects occur; in many instances such effects may be hazardous. These intensities range from 10 mW/cm^2 upwards (region of thermal effects).

(b) The range of subtle effects from about 1—20 mW/cm^2. In this range in part weak thermal but noticeable effects exist; direct field effects, as for example the phenomena of hearing pulsed fields; and perhaps, a group of other effects of a microscopic or macroscopic nature, details of which are at present unclearified (region of subtle effects or intermediate region).

(c) The region at intensities below 1 mW/cm^2. In this region thermal effects are improbable (region of nonthermal effects).

The boundaries indicated for these ranges are approximate and probably depend on numerous variable factors, such as animal size, threshold of warmth sensation, frequency, pulsing etc. The introduction of the intermediate range of subtle effects calls attention to the need for additional research, aimed at clarification of the underlying mechanisms.

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The proposal to divide microwave intensities into the above three ranges was supported by several speakers. A somewhat similar proposal was made previously at the symposium of the New York Academy of Sciences, held in New York in September 1972, on "Electrically mediated growth mechanisms of living systems". The three levels were termed non-thermal (1 μW — 100 μW); thermal, non-heating (100 μW — 10 mW) and heating (over 10 mW).

It was stressed that such limits are very relative and only further studies may make it possible to outline such limits more precisely. It was also stressed that relative species sensitivity should be considered in outlining such limits. A sort of sliding scale for species may be needed. It would be also most desirable to add one more parameter to the description of experimental conditions in microwave research, namely the absorbed dose expressed in appropriate terms to insure uniformity in published research. Significant discussion of this proposal took place among the participants with general support being given to it.

The widespread use of microwave power for industrial, civilian, and military purpose has greatly increased the possibility of exposure of large population in many countries of the world. Protection of exposed populations by means of health and safety standards has varied widely in different parts of the world, in largo measure because of differences in scientific theory and method.

Several papers (e.g. that of Dr. Michaelson) were devoted to the biologic effects of higher intensities. The majority of papers concerned the biologic effects of low intensities (e.g. that of Dr. Gordon and her collaborators). These intensities are so low that distinct thermal effects can be excluded. However, in a few of these investigations, the possibility exists that microthermal effects and nonthermal effects which are unclear at the present time might have occurred. These phenomena may be responsible for the biologic changes observed.

These investigations have been concerned with microwave effects in complex biologic systems. The use of medical methods of approach and the end results of the influence of microwaves were correlated with field intensities. These investigations did not permit explanation of the mechanism of microwave interaction with biosystems.

In addition to the general recommendations that are given at the end of the Proceedings (see p 334), the following specific conclusions and recommendations were agreed upon:

1. The majority of the investigations carried out at present use medical approaches. In this approach the microwave stimulus of interest is applied to the biologic system and the end result of clinical or biologic interest is registered. Biophysical investigations are also important. They concern up to now mostly effects on isolated components (e.g. membranes, molecules). A fairly advanced understanding has been achieved even though many problems remain unsolved. Only very few data exist on biophysical mechanism of microwave interaction with complex microscopic and submicroscopic systems (e.g. intermolecular mechanisms). This situation should be remedied. More biophysical investigations are needed before clarification and understanding of the subtle effects will be possible. Special attention should also be paid to investigations to determine the absorbed energy dose and its spatial distribution.

2. Investigations of the effects of low microwave intensities should be developed with the aim of determining threshold values at which biologic effects are induced. An evaluation should be made of the significance of subtle effects for biologic function. Combined effects of microwave and of other environmental factors should be investigated. Particular attention should be paid to investigations of bioeffects induced at various microwave frequency bands.

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3. Biologic, medical, and biophysical investigations of radiofrequency effects in the entire radiofrequency range should be carried out. Particular attention should be paid to the dependence of biologic effects on the physical characteristics of the electromagnetic field.

4. There is a need for further research to clarify and improve our understanding of the interaction of microwave and radiofrequency radiation with biologic systems at all levels of organization to provide and improve understanding of the full potential for: (a) cumulative effects, (b) delayed effects, (c) differential radiation sensitivity (i.e. sensitivity as a function of type of the system and the stage of development), (d) effects related to cellular transformations, (e) carefully controlled human epidemiologic studies.

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SESSION B. INFLUENCE OF MICROWAVE RADIATION ON THE NERVOUS SYSTEM AND BEHAVIOR

W. R. Adey, E. A. Lobanová, A. V. Roščin and W. A. G. Voss

Papers presented in this session emphasize difficulties inherent in evaluating subtle physiological and behavioral effects in mammals during and following microwave exposure. In part, these uncertainties relate to intercurrent stimuli, sometimes unsuspected during field exposures. They may elicit autonomic nervous reactions in the organism closely resembling field-induced changes. Moreover, long-continued, low-level exposures must take account, for example, of such natural factors as growth and aging, with consequent changes in endocrinologic status, before a causal role can be assigned to effects of microwave exposure. As with ionizing radiation, there are perplexing questions about cumulative effects and dose division. There are special problems in electrophysiological recording in the CNS during microwave exposure, since inappropriate metal recording electrodes may be associated with excessive energy absorption, and thus, with tissue heating and lasting damage. These concerns were explicit in the papers presented in Session B and in the ensuing discussion.

In her use of conditioning methods, Lobanova noted many changes in operant conditioned responses in rabbits irradiated for 1 hour daily in a field of 10 mW/cm^2 for 4 months, but not until the fourth month of exposure. Return to normal responses occurred only two months after irradiation. She reported that rats irradiated for 6 months became apathetic, often not responding, and failed to react to the quality of food. These findings typify the difficulty of quantitatively measuring such subtle effects, reminiscent of many similar reports by Soviet workers of effects of low-level exposures in man. Lobanova ascribed these effects to altered cortico-subcortical relations involving the hypothalamus, hippocampus and sensorimotor cortex, with a slow cortical EEG coinciding with convulsive hippocampal activity. Baranski and Edelwejn also implicated subcortical sites, and particularly the reticular formation, in their EEG and evoked potential records, which combined pharmacologic manipulation by phenactin, cardiazole and pentobarbital with chronic daily microwave exposure.

Findings by Goldstein and Sisko of an intense behavioral arousal in rabbits following brief irradiation at 9.1 GHz, with a response latency of 3 to 12 minutes, may be more difficult to interpret since the effects disappeared when the environmental humidity exceeded 40 percent. Could this be a peripheral effect on skin or fur, or is it mediated by some slowly activated central nervous humoral mechanism? If central, could the microwave field in central nervous tissue be enhanced by the presence of metal electrodes? The question of thresholds for thermal effects within the crania of test animals, with and without potential distortions of the EM field that might follow implantation of inappropriate metal electrodes, was repeatedly raised in discussion of these papers. It was pointed out that absorbed powers in the head of a rabbit could be in the range of 14 to 40 W/kg for exposure levels of 7 to 20 mW/cm^2, and that this might be 3 to 10 times above the threshold for thermally induced CNS effects.

The high general level of interest in the problems of instrumentation in studies of the central nervous system led to a separate informal session. It was agreed that recording of temperature during or immediately following irradiation of the brain would be of great importance. Several viewpoints were expressed on possible solutions to the

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problems of electrodes for bioelectric recording during exposure. It was suggested that saline filled glass electrodes with a metal ball at the tip might be feasible. Alternatively, wire electrodes, insulated with a high-quality dielectric, short with respect to the wavelength of the field and having a broad surface at the electrode tissue interface, might be suitable. Further research on electrode and electrode-amplifying systems was recommended.

To obviate the need for recording directly in the CNS, while retaining a useful measure of stress responses during microwave exposure, Justesen has used an "evoked colonic temperature". He noted that simply handling rats raised body temperature, and that this initial rise with handling was enhanced by microwave exposure. He interpreted these findings in terms of a Pavlovian orienting reflex to novel stimuli. This view was not accepted by Soviet participants, who emphasized the ephemeral character of an orienting response following the initial reaction to novelty.

In studying the effects of pulsed fields on animals with audiogenic epilepsy, Štverak, Marha and Pavkova emphasized the significance of the envelope of the carrier wave in seizure induction. This question of the significance of modulation envelopes in determining biologic sensitivity to the field has received very little attention, although recent studies by Bawin, Medici and Adey of low level UHF fields, amplitude modulated at 2 to 20 Hz, have shown their potency in modifying conditioned reflexes and EEG rhythms.

Romero-Sierra reported effects of 16 GHz fields at 25 mW/cm² on birds. These included altered EEG and EMG records, with increased high frequency activity. His findings also implicate the modulation pattern of the microwave carrier. These studies in behavioral neurophysiology were accompanied by evidence of concomitant structural changes in neuroglial-neuronal interrelations. Much further work is suggested by these proposed schemes of tissue interaction with microwave fields. They quite appropriately draw attention to recent developments in membrane structure, including the model of the "greater membrane", as proposed by Schmidt and Samson. The surface layers of glycoprotein that characterize the greater membrane may well be the site of threshold interactions with modulated microwave fields, in view of their strongly polyanionic character and capacity to reversibly bind water and divalent cations, particularly calcium. There is now much evidence that the initial events in excitation of the neural membrane may involve calcium in small shifts between closely adjoining binding sites on sheets of membrane surface macromolecules. Such a mechanism may underlie these interactions with weak electromagnetic fields.

Dr. Romero-Sierra mentioned certain possibilities of beneficial effects of microwaves. In this connection the work of Mr. Priore from Bordeaux was mentioned. Many participants expressed their interest in this work. Dr. Servantie very kindly supplied a list of references.*

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The reaction of the central nervous system to microwaves may serve as an early indicator of disturbances in regulatory functions of many systems. The extraordinary sensitivity of the nervous system to microwaves was clearly demonstrated by the findings presented in all the 6 papers, concerning this topic.

The investigations on the conditioned reflex function, behavior and differential reactivity of particular brain structures to microwaves are very important for the understanding of symptoms observed in personnel occupationally exposed to microwaves.

The data presented during this and other sessions are of great importance for the setting up of safe exposure limits, one of the basic problems in preventing untoward effects on the health of occupationally exposed persons.

The session recommended that further investigations on microwave effects in the nervous system should include:

1. Investigations on the influence of microwave exposure on behavior and conditioned reflex function using various exposure regimes. The results hitherto obtained indicate that such effects may depend on the exposure regime, but it should be stressed that possible relationships are insufficiently known.

2. Electrophysiologic investigations seem to be of particular interest. Such investigations carried out during the exposure period are particularly needed. Unified, standard electrodes permitting recording during exposure without interference from the microwave field should be developed. This is a task for an international cooperative effort. The results obtained by Dr. Guy indicate the need for such electrodes.

3. It is to be regretted that no data on the effects on central nervous system metabolism were presented during the symposium. Investigations, without which nothing can be said about the mechanism of the disturbances of regulatory functions of the central nervous system, are urgently needed.

4. A lack of data on morphologic changes in the central nervous system was also felt. Investigation on microwave effects of the electron microscopic, cytochemical and histologic picture of the brain should be carried out.

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SESSION C. EFFECTS OF MICROWAVE RADIATION AT THE CELLULAR AND MOLECULAR LEVEL

E. H. Grant, K. H. Illinger, B. Servantie and S. Szmigielski

Discussion of Dr. Schwan's paper was devoted to a number of fundamental points. The size dependence of the pearl-chain effect, with the voltages required to achieve alignment of macromolecules, cells and particles of 100 micron size, was discussed.

In principle, a wide range of particles may exhibit pearl-chain formation, but with threshold voltages critically dependent on particle size. For macromolecules voltages in excess of 10 $kVcm^{-1}$ are required; for cells and particles of 100 micron size, threshold voltages are of the order of 100 Vcm^{-1} and 1 Vcm^{-1}, respectively. The fact that the order of magnitude of the threshold for microwave hearing shows a dependence related to the pearl-chain effect was pointed out; the threshold is given by the expression: (400 mW/cm^2) (duty cycle)$^{-1}$. Fundamental to predictions concerning the dielectric behavior of membranes is the accuracy of the model employed. It was stressed that the currently accepted model, the Hodgkin-Huxley model, is consistent with the following behavior; requisite for the excitation of membranes by external EM fields are two conditions: a) the field strength must exceed the membrane firing potential, and b) the period of the field must equal or exceed the refractory period of the membrane. If any inadequacies exist in the Hodgkin-Huxley model, these criteria might not apply; in particular, other models for the nature of extracellular fluids may predict effects on membrane excitation through intermolecular rearrangement. The fact that dielectric saturation of biopolymers requires very large field strengths, of the order of 10 $kVcm^{-1}$, was adduced to explain the vanishing likelihood of protein denaturation by EM fields at low field strengths. The dynamic potential which exists in certain membranes, superimposed upon the average (static) potential, is not included in the assessment of interactions with EM fields, but the accumulation of energy in a membrane via external fields is inconsistent with the Hodgkin-Huxley model. As a general comment on the predictiveness of existing theoretical models, it was pointed out that there exists the possibility that effects at the level of biologic systems may not be predictable on the basis of the behavior of isolated molecular systems.

The question of the energy difference between conformational states of biopolymers was raised. As a general result, it was stressed that resonant interactions between EM radiation and molecules of biological interest are the more improbable the lower the frequency of the EM field; conversely, resonant interactions in molecular systems become paramount in the limit of high frequencies. Molecular collisions are strongly diabatic with respect to rotational and translation states, and strongly adiabatic with respect to electronic and vibrational states. Hence, EM radiation interactions are of the relaxation type at frequencies below 1 cm^{-1}, of the resonance type at frequencies above 100 cm^{-1}, and of an intermediate nature in the far-infrared region. As a result, EM fields in the microwave and RF region, below dielectric saturation levels, are unlikely to cause irreversible effects at ordinary *in vivo* temperatures.

Regarding the studies of microwave irradiation of biologic preparations represented by several papers, the effect of the shape and nature of the sample container, and of the depth of liquid, on the actual field in the sample was stressed repeatedly. Sample

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containers and the liquid in which the sample is suspended may act as dielectric lenses and/or reflectors and cause localized hot spots in the sample, which may render dosimetry inaccurate.

The question of the existence of cumulative effects in cataractogenesis by microwaves was discussed at some length. Michaelson argued for the re-examination of the concept of cumulative effects. It was also pointed out that latency times for cataractogenesis differ greatly from animal to man, and that the interrelation between injury and repair in the body renders a definition of a cumulative effect difficult. It was also stressed that errors of up to $\pm 70\%$ in the dosimetry can occur due to the characteristics of the body of the subject being investigated.

Dr. Baillie defended the concept of "cumulative effects" of microwave radiation from the medical point of view on a theoretical basis. If microwaves produce injury in tissue one cannot assume that the change is eliminated when the power is turned off. The return to normal (if a return to normal is possible) takes time. Accordingly and by definition, repeated exposure to microwaves may produce cumulative injury (whether functional, biochemical or structural) provided that the exposures are made with sufficient frequency. A progressive injury passing from functional through biochemical to structural forms is completely reasonable.

This standpoint was supported by Dr. Shore, who stated that while the question of cumulative effects was not a central theme of his presentation, Dr. Carpenter has obtained data demonstrating that single doses of microwave radiation which do not produce cataracts, become cataractogenic when they are administered daily for 15 consecutive days. He interpreted these data as providing evidence for a cummulative effect. Careful attention must be also paid to studies demonstrating that fetal effects which have been observed following relatively high acute exposures (Rugh) are also observed when animals are exposed to much lower levels of microwaves, but under conditions of chronic exposure (Gordon). These studies as well as the studies of EEG effects provide presumptive evidence for cumulative effects. This is, however, an important question that requires further discussion and research.

In connection with Dr. Stodolnik-Badańska's paper, it was proposed that the study be complemented by using Caspersen's technique for chromatids.

The problem of avoiding runaway heating in the microwave heating of frozen tissue was discussed in connection with Dr. Voss's paper; the essential role of cryoprotective agents and other means to avoid this difficulty was pointed out. The structure and dielectric properties of water in cryogenically cooled tissue were discussed.

The principal conclusions drawn from each of the six papers presented are as follows:

1. Biologic tissue exhibits three main dispersions:

(a) alpha-dispersion due to countersion movement about the charged cell surface and relaxation of the membrane properties.

(b) beta-dispersion due mainly to the membrane reactance but also partly to relaxation of monomolecules.

(c) gamma-dispersion due to free water; a small delta-dispersion exists between the beta and gamma dispersions due to bound water and to side-chain relaxation.

Analysis of electromechanical forces involved in biologic systems subjected to pulsed radiowaves and microwaves shows that the threshold for hearing effects in the middle ear is 400 mW/cm² divided by the square root of the duty cycle.

2. Resonance absorption phenomena are theoretically possible in biopolymers at around 30 GHz and are therefore a possibility in biologic tissue if the water content is low. Any such selective absorption of energy over a narrow frequency band would have important implications for the evaluation of microwave hazards.

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3. If washed rabbit erythrocytes are exposed to 3 GHz microwaves at a level of 1 mW/cm² the following efflux of substances is observed:

(a) the potassium after 15—30 minutes;

(b) the hemoglobin after 120—180 minutes.

With granulocytes the effect of the microwaves is to cause the appearance in the supernatant of acid phophatase and lysozyme. This occurs after 120 minutes of irradiation, also at 1 mW/cm² intensity.

4. In any experiments involving the effect of microwaves on animals, the importance of measuring power density properly should be stressed. In experiments carried out on the rabbit eye variation of such parameters as the animal's shape, size and ear position can affect the measured power density at the eye as much as 70%. The importance of well defined and well controlled experimental conditions is therefore quite clear.

Soon after the exposure of the lens to microwaves inhibition of DNA synthesis in the lens epithelium is noticed and decrease in ascorbic acid concentration observed. This happens before the opacities develop. It is therefore suggested that the microwaves interefere with lens metabolism.

5. The influence of microwaves radiation on human lymphocytes may be studied:

(a) when the lymphocytes are unstimulated,

(b) when the lymphocytes are stimulated to mitosis by PHA treatment.

In the former case the lymphocytes were transformed to blastoid forms and macrophage-like cells. In the second case mitotic anomalies were observed and were characterized by the occurrence of abnormal chromosomes and bridges between the chromatids and chromatid breaks.

6. Microwaves are a very effective way of re-warming deep-frozen organs and cells.

The method has been used with adult canine kidneys, fetal mouse hearts and tissue culture cells.

With the fetal mouse hearts recovered from — 196° by microwave heating, the electrical activity has survived in the majority of cases, and tissue culture cells have been found to withstand a very rapid rate of thawing.

Summing up this session, the following recommendation is made:

Work of the kind described in this session should be encouraged and further extended. To obtain reliable results, however, a multidisciplinary approach is essential. Such investigations should be tackled by a team of investigators comprising at least one of each of the following: doctor, biophysicist or physicist, and electrical engineer. Such a team may not necessarily be all located in one establishment: this may be too expensive to arrange on a wide scale. In this case inter-department collaboration is a satisfactory substitute provided all participants meet regularly.

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SESSION D. MEASUREMENTS OF MICROWAVE RADIATION

R. C. Baird, P. Czerski, A. W. Guy and M. Piotrowski

A clear understanding of the biologic effects observed in man, animals and biologic specimens exposed to electromagnetic fields requires a complete quantitative description of the fields both inside and outside the test subject. These fields are complex functions of the types of sources and the shape and size of the exposed subject or sample. If these effects are ignored estimates of absorbed power can be in error by several orders of magnitude. Above 200 MHz the combination of curved surfaces and high dielectric constant of tissues can produce very high localized internal absorption deep in the tissue due to focusing of the field. Below 200 MHz the absorbed power in exposed subjects drops sharply with frequency. In this range the unperturbed magnetic fields can produce far greater absorbed power densities in man than unperturbed electric fields of the same energy density, whereas the reverse is true in small animals. Internally placed metal or highly conducting probes can produce intense localized absorption due to the fringing of fields near sharp edges or points.

The external fields have usually been specified in terms of power density, but it was pointed out that this quantity is not always a good indication of the hazardous potential of a field. Further, existing instrumentation actually responds to the electric field or the square of the electric field, both of which are more reliable indicators of the possible biologic effects (except at the lower frequencies where magnetic fields may become more important). Three different types of meter were described.

The first, consisting of two thin-walled coated spheres connected by a small tube, is essentially a spherical bolometer and absorbs radiation in a manner similar to the human body. It responds to the average absorbed power and has been operated from 400 MHz to 35 GHz. This instrument is not manufactured commercially, but it may be worthy of further consideration. The second type of meter employs three orthogonal dipole-diode combinations to form an isotropic sensor that measures either the square of the electric field or each of the individual components of the field.

The advantages of this sensor are that it can be made very small (less than one cm in diameter), it is rugged and has a dynamic range in excess of 40 dB (a factor of 10^4). Models capable of being implanted seem possible. Peak power reading versions can also be constructed. The third type of meter uses an orthogonal assembly of thermocouples and also reads only the average power. It is incapable of reading peak power, but will function properly in a multifrequency field.

The necessity of accurate instrument calibration was emphasized. Such calibrations are essential for safety reasons and to provide a reliable basis for comparison of the experimental results of various laboratories. Three basic approaches to the calibration problem were discussed — the free-space standard field method, guided wave methods, and the standard probe or transfer standard method. All of these methods can be used for reasonably accurate calibrations if sufficient care is taken, but one must be aware of several problems in each method. Calibration accuracies of about 3 to 10 percent can be achieved, depending on the method used and the instrument being calibrated. However, one cannot expect such accuracy when using the meters for actual measurements because (a) meters are usually calibrated in plane-wave fields

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and such fields are seldom encountered in practice, (b) in most calibration methods only the sensor is exposed to the field while in practice the entire instrument, including interconnecting cables, is immersed in the field, and (c) with hand-held meters, the presence of the operator will perturb the field and affect the reading. These uncertainties are difficult to assess, but an attempt should be made in each situation.

Internal fields and power absorption may be directly measured *in vivo* by implanted electromagnetically transparent probes, although accurate and reliable implantable probes still need to be developed. Internal power absorption can also be measured using thermographic techniques on phantom models or sacrificed animals. This is done by thermographically observing related temperature changes in bisected sections of the model or animal after a short exposure to an electromagnetic field.

In connection with internal fields and power absorption the problem of perielectrode energy absorption in brain tissue was discussed at some length. Dr. Guy was of the opinion that the energy concentration and the resulting thermal gradient at the tip of the electrode is a function of the impedance of the leads and amplifier as well as of the electrode-tissue interface impedance. Though simple impedance considerations may be used to quantify the thermal gradient for quasi-steady conditions, the complexity of the model for microwave exposure requires a rigorous solution of the EM equations for antenna buried in lossy media (see for example the special IEEE PGAP, *Transactions on antennas buried in lossy media* published about May, 1962). In general any time a sharp metal object is put in contact with tissue, field enhancement will result at the point of contact.

The thermograph presented in Dr. Guy's study used an electrode described by A. H. Frey, in "Brain stem evoked responses associated with low intensity pulsed UHF energy". *J. Appl. Physiol.*, vol. 23, pp. 984—988, Dec. 1961. The electrode was connected to a lead several feet long. The electrode was placed 2 to 3 cm deep or approximately one half wavelength or more into the medium.

At microwave frequencies with wavelengths of the order of centimeter in tissues it may be difficult to isolate insulated electrodes in this manner. Certainly some studies should be carried out to see to what extent the enhanced fields may be treated as a function of electrode properties.

Interference or diffraction patterns produced when a human subject is exposed to a microwave field of 1 to 3 GHz were described. These studies show that the field is strongly perturbed by the subject. Consequently, in experiments involving more than a single animal one must be careful to space the animals sufficiently far apart so that one animal does not perturb the field in the region of another animal. These results also illustrate the effect that an operator can have on the field he is trying to measure when using a hand-held probe. This is one factor which is hindering the development of a reliable personal dosimeter. Reflection and transmission measurements of this type will also allow a new approach to the estimation of absorbed energy in different parts of the human body.

A simplified method of determining the radiation hazards associated with moving radar antennas was described. The method avoids the tedious measurement procedures used previously by employing assumed radiation patterns which are based on selective measurments. These assumed patterns are used to calculate the field intensities at points of interest. The method was applied to rotating and scanning antennas, and is applicable to the evaluation of situations involving several radiating sources operating at the same time.

There is a need for complete data on the dielectric properties of biologic substances, and a method for determining the dielectric constant of samples placed within

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a cavity resonator was presented. The theoretical approach and the experimental apparatus were described. Both the real and imaginary parts of the dielectric constant were obtained from measured values of the resonant frequency and the Q (quality factor) of the cavity. Measurements of various samples were carried out at the X-band.

The following recommendations were approved by the participants involved in microwave measurements:

1. Accurate, internal dosimeters are needed for biologic research. Efforts should be increased to quantify internal fields in future work.
2. Standard methods of quantifying internal and external fields and detecting the biologic signals should be established.
3. Standardized exposure techniques for animals and *in vitro* samples would significantly improve our ability to compare results between different laboratories.
4. Researchers should describe all pertinent experimental conditions, including the size and shape of test samples, etc.
5. The development of magnetic field sensors should be promoted in view of recent indications of strong interaction with the magnetic fields at frequencies below about 200 MHz.
6. More complete information on the electromagnetic and thermodynamic properties of biological materials are needed. The development of techniques for measuring these properties in a non-destructive manner on living organisms would be extremely useful.
7. An interdisciplinary group should be established to translate and disseminate documents pertaining to both the biologic and engineering (physics) aspects of research on the biologic effects of electromagnetic radiation.

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SESSION E. OCCUPATIONAL EXPOSURE AND PUBLIC HEALTH ASPECTS OF MICROWAVE RADIATION

Z. Edelwejn, R. L. Elder, E. Klimková-Deutschová and B. Tengroth

The difficulties of rigidly controlled clinical and epidemiologic studies were discussed, particulary in long-term studies. Since at present no reliable methods and equipment for individual dosimetry exist, the exposure of microwave workers must be estimated on the basis of measurements made at working places and mean daily (weekly, monthly) duration of exposure. In many instances this may be difficult, as for example in cases where the individuals exposed move about and work with moving microwave beams. The type of work should be taken into account. Depending on the type of work, exposure to near or far fields may predominate, which influences the reliability of dosimetric data. Possibilities of incidental or accidental (high level) exposures must also be estimated.

Particular attention should be paid to possible effects of other environmental factors which may occur at working places where microwave equipment is used. Two factors were mentioned specially during the discussion: ambient temperature (microwave welding) and exposure to X-rays, generated incidentally by many parts of microwave apparatus.

Dr. Sadčikova stressed that all these considerations were taken into account in the studies that she had described. In particular the ambient temperature was not elevated and X-ray exposure was controlled. It may be stated that the microwave workers examined in her studies were not exposed to incidental X-rays. It should, however, be stressed that the persons examined began their work before the present USSR safe exposure limits were introduced. Because of this the "occupational case history" includes periods of exposure which were higher than allowed by the present USSR regulations.

During the discussion it was also stressed that no serious cardiovascular disturbances were ever seen in man (or in experimental animals) as the result of microwave exposure.

According to the authors and discussants, most of the significant clinical findings (subjective complaints, physical examination, bioelectric recordings) in the case of microwave long-term exposure or overexposure are referable to the nervous system. The term "microwave neurosis" was mentioned.

A lively, but inconclusive discussion concerned microwave lens injury. According to Dr. Zaret microwave cataracts are characterized by typical traits, seen on ophthalmologic examination and easily recognizable. According to Dr. Żydecki long-term microwave exposure may cause an "acceleration" of the normal aging process, and more opacities and discrete lens changes are to be seen in microwave workers than in comparable age groups. No characteristic morphologic traits are, however, to be found. Dr. Appleten confirmed his results published earlier (*Arch. Ophthalmology,* 88, 259, 1972) that no differences in lens translucency between microwave workers and comparable age groups of unexposed persons can be found. These results are additionally confirmed now by examination of about 1500 military personnel working with microwave equipment. No explanation of these differences could be found. Particular

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attention should be paid to retinal lesions in microwave workers, the general impression being that such lesions could have been overlooked in earlier studies.

In the papers on microwave eye damage the problem of cataracts seems to dominate. Whether the cataracts observed are of a special type or not, cannot be clearly defined. There seems to be convincing evidence that opacities in the lens occur among microwave workers. It is suggested but not proven that this is a result of exposure to microwaves. In most microwave workers investigated, where opacities have been demonstrated, these changes have no clinical significance. However they may be of great importance as they may be signs of a developing cataract. Retinal changes have been reported. In order to understand these eye changes further epidemiologic studies should be carried out in combination with theoretical and experimental work. There seems to be no evidence that these changes are anything but thermal in origin.

The above discussion led to a consideration of the problem of adequate control groups. No satisfactory solution could be offered. It is extremely difficult to find human groups differing only in one variable — degree of microwave exposure or exposed and unexposed groups indentical in other respects. All medical epidemiologic studies involve similar questions and doubts, requiring final experimental verification.

The specificity of the clinical symptoms of microwave effects was illustrated in several groups of occupational exposure according to the clinical picture. Autonomic disorders and cardiovascular and hemodynamic functional disturbances were emphasized. The neurologic picture may indicate the possible hazards in the working environment. Computer analysis of large groups according to various types of exposure and clinical symptoms, electrophysiologic and biochemical results make it possible to obtain information on the quality, main stages of involvement and localization of lesions in the nervous system. The problems of the mechanisms operative in disturbances of the nervous system may be explained by the rectangular branching of vessels leading to the brain stem and to the temporal region, with slowing of the blood flow and decreased oxygenation. A thermal effect can be assumed to be responsible for the symptomatology of the fossa posterior. Methodological aspects of examination were emphasized. Preventive measures may be deduced from clinical results and criteria can be established for persons to be excluded from work with microwaves.

Attention has been paid to biochemical changes, such as glucose tolerance, pyruvic and lactic acid levels as well as of creatinine in the urine, blood protein with precise correlations to the working conditions, the levels of cholesterol, 17-ketosteroids, etc. In most cases biochemical changes may be attributed to changes of regulative mechanisms.

A very lively discussion was concentrated on thermal effects and unspecific influences in working conditions and on the problem of biologic effects and health aspects in the population, where the hazards of microwave and ultra-high-frequency electromagnetic fields may play a role in living conditions.

On the basis of the clinical studies presented the following recommendations were made:

1. To seek further suitable preventive measures not only for persons exposed to microwaves at work but also for the general population in possible danger.
2. To make further epidemiologic comparative and dynamic studies.
3. To stress the evaluation of refined tests of motor system function as a diagnostic tool for the estimation of the exposure to microwaves.
4. To include the examination of the retina in all ophthalmologic examinations.

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SESSION F. PRESENTATION AND DISCUSSION OF SESSION REPORTS, CONCLUSIONS (INCLUDING FUTURE RESEARCH NEEDS) AND RECOMMENDATIONS

J. C. Gallagher, K. V. Nikonova, E. Shalmon and C. Susskind

Only a single paper was presented during this session. Dr. Grant pointed out that microwaves can be used as tools in biological research. He described some of the recent research in his laboratory in which the dielectric constant of lipoproteins from patients with hyperbetalipoproteinemia (a condition associated with coronary heart disease) was compared with that of normal lipoproteins. Measurements on other macromolecules were also described. These experiments may serve as examples of research topics to be investigated in the future.

A discussion on bound water in tissues ensued. Eye tissue contains a substantial percentage of bound water. Dr. Oderblad, Sweden, has conducted studies by NMR (nuclear magnetic resonance) on bound water. Professor Schwan has also carried out dielectric relaxation studies on eye tissue. The determination of bound water by NMR studies does not give the same result as does dielectric relaxation, but gives an indication of it. The outer segments of the rods and cones in the retina consist of small quantities of water. The content of bound water in this region has not been studied and should be investigated. This would highlight the importance of any bound water and increase the probability of resonance absorption effects.

The second part of the session was devoted to presentation by the respective Chairmen of the session reports, conclusions and recommendations. These concerned mainly future research needs and directions. Many speakers supported the conclusions reached at particular sessions. The general feeling was that for further development of research on microwave bioeffects international collaboration and coordination of efforts under the auspices of an appropriate international agency are most important. The most significant points of the conclusions and recommendations were selected and are presented under a separate heading in this book (pp. 334—335).

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EXPRESSION OF APPRECIATION

Professor A. V. Roščin, USSR, addressing the Symposium on behalf of all the participants, said: During the past four days, we have all participated intensively in the work of the first International Symposium on Biologic Effects and Health Hazards of Microwave Radiation. For us, who are specialists working toward the protection of man from the harmful effects of such radiation, the Symposium has been an event of very special and lasting importance.

The British author Bernard Shaw once said that if two friends exchange apples, each still has only one apple, but if they exchange ideas, then each has two ideas. The importance of our Symposium lies in the fact that it has provided us with an opportunity to exchange ideas and opinions about what has been done in the past and what we have to do in the future.

When I made plans to attend the Symposium, my past experience of similar meetings made me afraid that there would be a wide divergence of views because the scientific problems posed by microwave radiation are still very new; they have been a matter of concern for only a little over twenty years.

Thanks, however, to the very able and judicious organization of the Symposium, it has been possible for us to combine the many different streams of knowledge, springing from sources all over the world, into a single river flowing along a clearly determined course. This happy result will undoubtedly be highly stimulating for further work in the field of microwave research.

I would like to stress here the important role that the Polish co-sponsor played in the successful organization of the Symposium. The Poles are noted for their hospitality and talent for international collaboration and they have displayed these qualities briliantly in the present Symposium. I feel that we all have reason to be deeply grateful to our Polish hosts, the official Polish organizations and the Polish co-workers for the contributions they have made to the success of the meeting.

I have also been greatly impressed by the goodwill of the American co-sponsor, who has played such an important part in the organization and work of the Symposium. I could go on to enumerate the many other countries that have also participated and whose representatives have brought along knowledge and shared it freely with us all. It is obvious that a vast amount of goodwill has been demonstrated by all the speakers.

Dr. R. L. Elder, USA, proposed that the participants express their thanks to the principal hosts and sponsors of the Symposium and their staff, with deep appreciation of the excellent arrangements made for the Conference, which had contributed so much to the spirit of goodwill and cooperation prevailing during the discussions. The proposal was approved unanimously.

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CONCLUSIONS AND RECOMMENDATIONS

The widespread and increasing use of microwave power has greatly increased the possibility of exposure of both occupational and general population groups in many countries of the world. Protection measures and health and safety standards have varied widely in different parts of the world mainly because of differences in research approaches, findings and interpretations. In so far as possible, it is imperative to resolve or remove obstacles to a common understanding of the scientific basis for protective measures.

The accomplishments of this memorable international symposium, in terms of meaningful exchange of data, frank discussion of viewpoints, enthusiastic interest in opportunities for collaborative undertakings, and the recommendations that follow, constitute a significant step toward the advancement of knowledge in the field.

The following recommendations were made:

1. To promote international coordination of research on the biologic effects of microwave radiation there should be a continuing exchange of information, improved efficiency of translation services, exchange visits, and closer collaboration in research projects and publications.

2. A program concerned with non-ionizing radiation should be developed by an international health agency that could exert leadership in this field and facilitate communication among scientists. It was hoped that the World Health Organization would assume this responsibility.

3. Every effort should be made to establish internationally acceptable nomenclature and definitions of physical quantities and units and to standardize measurement techniques and dosimetry. An international group should be established to work out procedures for achieving these objectives.

4. To achieve a more uniform approach to the discussion of mechanisms underlying biologic effects, it is proposed that microwave intensities be considered as divided into three approximate ranges as follows:

a) The range above 10 mW/cm^2 in which distinct thermal effects predominate.

b) The range below 1 mW/cm^2 in which thermal effects are improbable.

c) An intermediate range in which weak but noticeable thermal effects occur as well as direct field effects and other effects of a microscopic or macroscopic nature, the details of which have not yet been clarified.

The limits of these ranges have not yet been determined. They may differ for various species and may also depend on a variety of parameters, such as modulation and frequency.

5. In view of the importance of electrophysiological recording for studies of microwave effects there is need for the development of new electrode systems and integrated electrodeignal amplifying systems capable of use and full operation during microwave exposure.

6. Further biologic, medical, epidemiologic and biophysical studies are needed to improve understanding of the interactions of microwave radiation with biologic systems and clarify the risks that may be associated with microwave exposure. Specific attention should be given to the following:

a) investigation into the occurrence of cumulative effects and delayed effects;

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b) study of low-intensity effects;
c) determination of possible threshold values;
d) study of combined effects of radiation and other environmental factors;
e) investigation of differential radiation sensitivity as a function of organ system and age or intrauterine development;
f) study of effects related to cellular transformations;
g) study of effects occurring at the molecular level; and
h) determination of absorbed energy dose and its spatial distribution.

The desirability of conducting similar investigations in the radiofrequency range was emphasized.

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