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MICROWAVE MAGIC

J.B. BATEMAN

17 NOVEMBER 1977

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This is a report, with critical comment, of a meeting convened by a microwave research department within the French national research center for space and aeronautics in order to present the results of current French research on the biological effects of microwaves. The report proper is preceded by notes on the sponsoring organizations and by critical remarks on a series of papers describing the remarkable biological properties of the physically uncharacterized radiation emitted by an apparatus assembled by the inventor A. Priore. The

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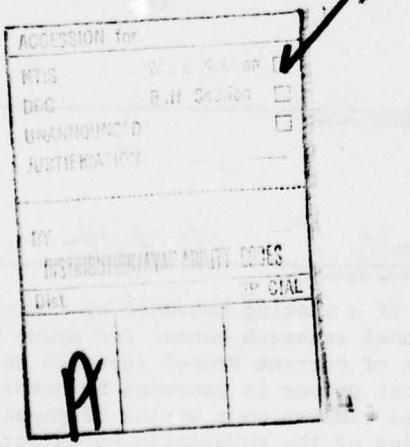
topics discussed ranged from specific effects of microwaves on microorganisms and on the vertebrate central nervous system, to discussions of microwave thermography and microwave heating in the diagnosis and treatment of cancer. The empirical approaches generally used deflected attention from any thoroughgoing attention to the vexed question of thermal versus non-thermal effects, although a useful distinction was drawn between the conditions under which non-thermal effects might be detectable and those under which such effects would be obscured by temperature changes.



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MICROWAVE MAGIC

MICROWAVES: A PANDORA'S BOX?

The panorama of electromagnetic waves stretches as far as we care to think, but the sea of radiation in which we are naturally bathed greatly favors certain waves while others are so faint as to be scarcely detectable. Some are known to be present because we are equipped to sense them; others can be demonstrated because they are seen to affect things going on around us or to influence instruments that we have constructed. The rest are essentially artificial, available for practical purposes only when we have found means of generating and measuring them. As each new bit of the infinite panorama is revealed in this way new techniques are invented (or were predicted) for the waves. Inevitably some radiation escapes in the course of utilization, either through inefficient handling or in the nature of the use to which it is being put. So we always have to ask whether some unforeseen danger has been ushered in by the new technology. What effect, in particular, may it have on our own physical and mental well-being? The memory of the victims of ignorant or reckless exposure to x-rays is still in our minds as an example of unsensed peril.

In the case of radio waves, casual thinking about the quantum aspects of electromagnetic radiation has sometimes led to a sense of security that might prove to have been ill-founded. The radio-wave quanta, it has been said, are too feeble to do much damage unless, indeed, there are so many of them that we fry in our own fat. If this were true, a sensation of heat would provide the necessary warning and we would move away just as from a fire.

The argument is fatuous on two currently valid grounds. The absorption of radio waves by biological tissues is non-uniform. Selective heating may produce undesirable (or beneficial) effects before any sensation is elicited. Second, recent advances have expanded the available frequency range, and the range of important applications, into a region in which knowledge of the mechanisms of interaction with matter is still fragmentary. Even in the later days of short-wave radio there were arguments about possible specific, or non-thermal, effects, many of them since discredited. In the microwave region now being extensively explored and utilized, from about 3 to 300 GHz (3×10^9 to 3×10^{11} cps), we are approaching the time scale on which nanosecond and picosecond chemical and photochemical kinetics are being studied. It would be rash to contend that on this time scale nothing of biological significance can occur as an alternative to dissipation by thermal collision.

The biological action of microwaves is being explored with much enthusiasm, for in addition to a certain amount of magic and a bit of witch-doctoring associated with "specific" effects, there are substantial

industrial, scientific and medical possibilities and some tantalizing phenomena, apparently non-thermal in nature, that demand elucidation. The countries most intensely involved are the US, France, and the USSR.

A FRENCH SYMPOSIUM ON MICROWAVE BIOLOGY: ORGANIZATION

Current French work was presented recently at a meeting sponsored by the Ecole Nationale Supérieure de l'Aéronautique et de l'Espace (ENSAE) and the Centre d'Etudes et de Recherches de Toulouse (CERT) under the presidency of Monsieur Maurice Ponte, Membre de l'Institut, and the patronage of the Institut National de la Santé et de la Recherche Medicale (INSERM) and of l'Electricité de France. The organizers were Professor Léo Thourel and Mr. A. Priou of the Département d'Etudes et de Recherches en Micro-Ondes (DERMO), one of the seven research departments comprising CERT. The meeting was held at CERT, situated just outside Toulouse, on 5 and 6 July 1977.

A NOTE ON ENSAE AND CERT

Just to complete the picture I should add that ENSAE and CERT, housed in a single campus, are linked, so to speak, by one official, Dr. Marc Pelegrin, who serves as Director of ENSAE and Administrator of CERT.

The overall sponsorship of ENSAE comes from the Minister of the Armed Forces (Ministère des Armées). The school, a member of the élite Grandes Ecoles Françaises d'Ingénieurs (see "France's Grandes Ecoles," by A. Barcilon, ONRL R-11-76), is responsible for the training and research specialization of engineers highly qualified for entry into the aerospace sector of industry when there is a requirement for advanced techniques.

CERT, while answerable to the Director General of the Office National d'Etudes et de Recherches Aérospatiales (ONERA), is linked to ENSAE by the obligation to carry out advanced applied research in areas covered by the training programs of ENSAE and to offer to the graduates of the school the means of becoming research-oriented and the facilities for specialization. At the same time, CERT enjoys a certain degree of autonomy by financing more than 80% of its activities from research agreements with industrial enterprises, public organizations, national services, and local authorities.

The dual responsibilities of instruction and research are met by the seven departments of study and research (DER) already referred to. These are: aerothermodynamics, automation, information, measurement, microwaves, optics, and space technology.

In the context of this report one sees that the Centre offers a remarkable range of expert consultation for those working in the microwave department, DERMO. The Department itself is organized around four working groups dealing with antennas and radomes, components for hyperfrequencies, effects of microwaves on matter, and industrial applications of hyperfrequencies.

MICROWAVE BIOLOGISTS IN AND AROUND CERT

CERT was a most appropriate place for a representative gathering to discuss the biological effects of microwaves. There is within DERMO, as part of the working group dealing with the effects of microwaves on matter, a small unit working on biological effects. They are favorably placed in the forefront of physical research on microwaves. However, being at some disadvantage in regard to biological expertise, they must often go elsewhere for biological and medical advice in return for which they are in a position to assist in the solution of physical problems facing their colleagues in the medical schools and universities. This may not be the ideal way to do biophysical research, but it may be a means to avoid the most elementary pitfalls. It was evident during the meeting that there was a general awareness of the difficulties; so acutely so, indeed, that the outlook was largely empirical. There was much emphasis on facts and little or no discussion of mechanisms.

WHO IS INTERESTED IN MICROWAVE BIOLOGY?

Seeking a clue to the reasons behind current concern with biological effects of microwaves, it is useful to take a quick look at the audience at the recent symposium (see Appendix II).

Naturally DERMO was heavily represented, with 23 out of a total of about 108 persons. Seven came from University departments, 15 from medical research units, 6 from other research institutes, 3 from the naval research laboratories in Toulon. The French government was represented by two persons from the Direction de Recherches et Moyens d'Essais (DRME), the research directorate of the Defense Ministry, which has for some years supported research on microwave effects at CERT and at five or six centers elsewhere. The Ministry of Health had a representative; then there were three from regional agricultural authorities, and two from the central research funding organization DGRST (Délégation Générale à la Recherche Scientifique et Technique) which, like DRME, has supported work at CERT. A wide range of commercial interests was covered by at least 15 of those present. They included the French research representative of British Petroleum who was interested in the possible use of microwaves in the BP process for the bacterial conversion of hydrocarbons to protein, a project which appears to be temporarily on the rocks despite

its alleged superiority to the Imperial Chemical Industries process which first converts the hydrocarbon chemically to methanol. The pharmaceutical laboratories of Rhône-Poulenc were embodied in the person of a doctor who said that he had just set up a contract with the Institut Pasteur for non-thermal sterilization by microwaves. A very long shot indeed, unless he has information not generally available! A gentleman from Nestlé in Switzerland was the only foreigner present except for the two from ONR and ONRL. That leaves about 30 unaccounted for because I could not decipher the acronyms, ranging from ENSEIHT through CRAM, CRACM, CREST and CHU to IUT and SNEA, to mention only a few.

A FRENCH SYMPOSIUM: TECHNICAL REPORT

In the following paragraphs I shall mention some of the topics discussed on 5-6 July 1977 and some of the results reported, using a rough-and-ready classification. The papers (see Appendix I) were given in French and no abstracts or preprints were provided. As mentioned above, there was little attempt to go beyond the initial empirical observations, and while many experiments were done at low field intensities, sharp demarcations in terms of thermal and non-thermal èffects were seldom attempted. My reports have benefited, in the case of papers given by members of DERMO, by a visit to the laboratories on 7 July.

Microwave Research in the US and France

The close liaison between French and US microwave research workers was evident from the presence of Dr. Thomas Rozzell of ONR, who gave two papers and was honored with the "presidency" (chairmanship) of one of the technical sessions. He was widely praised for the clarity of his papers which were delivered in a measured, precise English which must have been understood by everyone. At the end of the meeting A. Priou (DERMO) surveyed the programs of several US workshops, past and future, on microwave biology and tumor magnetophysics.

In his first paper Rozzell simply gave an overview of US programs, their funding and their country-wide coordination by the Electromagnetic Radiation Management Advisory Council. Of particular significance for the French listeners was his insistence on the need to move beyond the mere recording of phenomena to an understanding of primary mechanisms at the levels of the cell, the cell membrane, and the molecule. This fundamental change *vis-à-vis* the majority of existing US investigations carries with it certain rigorous technical requirements of which the most important are: (1) Exploration of the entire range of frequency between zero and several hundred gigahertz, rather than confining attention, as hitherto done, to the two agreed fixed frequencies, 0.9 and 2.45 GHz. (2) Special emphasis to be placed on the higher frequencies, especially on the X-band, 8-10 GHz, and the band 40-60 GHz. (3) Dosimetry to occupy a key position in all microwave research.

The French microwave scene, past and present, was presented by B. Servantie (Centre de Recherches d'Etudes et de Recherches de Biophysiologie Appliquée à la Marine, Toulon) who attempted to "put a few ideas into their proper place," starting from the realization in 1943 of the dangers of radar and the support by the RDRME of six French laboratories in order to assess these biological hazards.

Servantie's approach to the apparent contradiction between the attribution, especially in the US, of all microwave effects to heat and the claims of others, notably in the USSR, to have detected far-reaching non-thermal effects, is to suggest that the conditions chosen for experiments designed to explore the two viewpoints are mutually exclusive and therefore cannot be contradictory. The point is illustrated by classifying reports claiming, or denying, specific (non-thermal) effects in terms of dose rate and duration of exposure. The majority of specific effects seem to require for their manifestation long-term exposure to low power densities (probably $<<20$ mW.cm^{-2} for $>>24$ h). The majority of negative results have been obtained by brief exposure to much higher power densities, and more prolonged exposure to such fields leads to thermal death. Nevertheless, Servantie recognizes that the distinction often drawn between thermal and specific effects is somewhat arbitrary and has not been shown to correspond to physical reality.

Servantie then gave a few examples of recent studies in France not reported in detail at this meeting. These included: (1) The discovery at the University of Rennes that exposure of small animals for 15 days to microwaves at a 500-Hz pulse frequency results in a statistically significant loss of weight of the adrenal glands of about 10%. (2) The published results of Berteaud *et al*[1] confirming (in part) Russian claims of frequency-selective effects on the growth of *Escherichia coli* exposed to power densities around 10 mW.cm^{-2}, with pronounced inhibition at 70.5 and 73.0 GHz within the range 70-75 GHz. (3) Unpublished data by Dietrich Averbeck (Fondation Curie, Paris) showing distortion of the first-order x-ray-caused decay curves of yeast by prior, or simultaneous, exposure to 73-GHz radiation at low power densities. Averbeck, present at the meeting, preferred not to give these results in detail pending completion of the work. (4) A brief account of several incidents at Toulon in which alarming symptoms could be attributed to exposure of personnel to microwaves. (5) Mention of the work of A. Priore and collaborators in Bordeaux using mixed radiation of unspecified composition. Some of the results were characterized as surprising, but extremely important and interesting. In particular, the impressive results obtained by R. Pautrizel (Univ. of Bordeaux) were mentioned approvingly. Pautrizel had shown that rodents infected with the causative organism failed to develop trypanosomiasis when irradiated by Priore's machine and became immune to further infection. Pautrizel himself, although present, did not give a paper.

A Ghostly Presence: "L'Affaire Priore"

The evocation of the absent Priore (sometimes spelled Prioré to approximate the Italian pronunciation), or his spirit, was more than an empty gesture, for the "affaire Priore" probably stimualted the interest of the French defense authorities in microwave biology and thus, directly or indirectly, gave rise to much of the work reported at the CERT meeting. A brief account of the matter is therefore in order at this point.

The scandalous details were reported in full color by D.S. Greenberg, Washington Editor of the *Saturday Review of Science*[2] under the title "The French Concoction." Greenberg's article verged on the improper by including damaging statements attributed to British cancer scientists who did not wish, or were not permitted, to identify themselves. Such evidence is best treated as scuttlebutt and in what follows I shall refer only to reports in the scientific literature.

The several papers in *Comptes rendus* from A. Priore (alias Prioré) and collaborators[3-12] provide impressive evidence that the radiation given forth by a series of "black boxes" assembled by Priore can cause certain implanted animal tumors to regress, can prevent the development of fatal disease in rodents infected with trypanosomes and—in so doing—stimulates the immune response of the host. The biological evidence is there to be examined, and I shall not try to reproduce it here.

When the second paper was presented[4] to the Académe des Sciences, its sponsor, Dr. Robert Carrier, defended the reputations of the several biologists involved and described the measures taken to erase all possibility of fraud. He expressed the hope that the inventor of the black box would eventually see fit to allow disinterested physicists to examine the apparatus at leisure. Science, he said, would not know how to tolerate devices enshrouded in mystery.

Brave words. But the black box has not yet leaked its secret. Reading the various descriptions of its properties one suspects deliberate obfuscation. For example:

In ref. 4:

> "The apparatus . . . is a generator of superimposed magnetic fields having a wavelength between 3 and 80 cm, and associated with a system of oscillatory waves of low and high frequency. The whole is guided in a rotating emission tube in unidirectional electromagnetic fields of variable intensity, modulated at a wavelength between 1 and 18 m. The maximum intensity of the electromagnetic radiation at present reaches 620 gauss . . . . The detailed description of this apparatus will be the subject of a further communication. The physical principle has been the subject of a patent (PV 899-414)."

* Since writing these notes I have received a copy of the French patent (French Application No. PV 899-414, now Patent No. 1,342,772, 7 Oct. 1973) and several other documents. I have also visited the installation at Floirac (Bordeaux). A further report is being prepered.

In ref. 6:

> "The apparatus employed . . . is a generator of electromagnetic fields which we localize by a magnetic field of maximum value 620 gauss."

In ref. 8:

> "This apparatus is a generator of electromagnetic waves and of modulated magnetic fields starting from: a discharge tube containing a rare gas, provided with a cathode and an anode of special form; devices for excitation with static electric fields and with attenuating electric fields of high frequency and of very high frequency; axial and transverse magnetic fields created by use of a variable frequency modulator and a source of direct current of moderate strength . . . . The frequency of pulsations of the magnetic field is between 0.5 and 2 Hz."

Reference 9 reports use of a new apparatus with a magnetic field of 1240 G.

By 1971 there were signs that Carrier's appeal for full disclosure might be heeded. The black box remained inviolate, to be sure, but a physicist of repute was permitted to collaborate in a study of the physical nature of the box's emissions and in some additional biological experiments that the biologists themselves might not have thought of. The authors of the short paper[10] evidently withheld more than they released and they failed to promise a more detailed exposé. One must be thankful for small mercies. Still, it is tantalizing to read in the opening par paragraph:

> "Detailed analysis of the rays emitted . . . (over a range) . . . extending to frequencies corresponding to X- and γ-rays has shown the essential presence of a pulsed UHF electromagnetic wave of 9.4 GHz, amplitude-modulated at an HF frequency of 17 MHz, whose spatial distribution we have determined in a plane perpendicular to the axis of the apparatus. We have also observed the existence, and the distribution, of a slowly modulated continuous magnetic field of order of 1 kGs."

In the experiments then reported, groups of mice infected with *T. equiperdum* were exposed to the energy in "wave-guide" cages placed at various distances from the axis and hence, according to the statement just quoted, subjected to different intensities of the microwave component. The results, although presented in a sketchy way without appropriate numerical examples, confirm the previously reported effects of the field in reducing the parasitemia. They also show this protective effect to become less marked as the cages are moved away from the axis of the beam, until at about 20 cm off-axis it is reversed; the parasites multiply and the animals eventually die.

The results are expressed in terms of a simple parameter giving a measure of the rate of increase or decrease of the number of parasites in the animal's blood. The values of this parameter vary regularly with microwave-field strength and duration of exposure. The range of average rates of microwave energy input is shown graphically as 0-700 μW (per cage? per animal? per cm^2?). The values must be multiplied by 1.45×10^3 to give the unit pulse strength.

The authors conclude that these experiments show the microwave radiation at 9.4 GHz to be essential for production of the observed biological phenomena, but not necessarily sufficient or even of predominating importance. Indeed they report, without further details, that in an experiment with pure nonmodulated microwaves of frequency 9.4 GHz and comparable energy, animals infected with *T. equiperdum* all died.

The unstated assumption beneath the main conclusion must be that the spatial intensity distributions of the nonmicrowave components present in the emission from the Priore apparatus are quite different from that of the investigated microwave component. This assumption is neither substantiated nor is any mention made of measures that might have been taken to eliminate other components or of effects that the waveguide cages might have on their distribution. These omissions are all the more regrettable in view of the opening statement already quoted, which invites the suspicion, without further nourishing it, that ionizing radiation may be important in the biological effectiveness of the device.

It is easy to see that such incomplete disclosures place French microwave biologists in a dilemma. In a sense, the work reported at the CERT symposium represents their unavowed response to the challenge.

Dosimetry and Physical Measurement

Although Rozzell had stressed the key importance of dosimetry in work with microwaves, there was during the meeting neither any general discussion of this subject nor very much information of a critical nature on the means used in the various studies in support of statements made about field strength profiles in and around experimental test objects, rate of energy absorption, distribution of temperature change within test objects, and bandwidth and constancy of applied frequency. The only topic dealt with in any detail was that of "noninterfering" thermometric probes for use in microwave experiments.

The paper by Rozzell described the principles of the probes available, or under development, in the United States. The liquid-crystal optic-fiber probe developed at the University of Utah is commercially available as Model LCT-1 from Ramal, Inc., POB 275, Sandy, UT 84070. Light passing down the fiber bundle to the tip of the probe is reflected by a mixture of cholesteryl chloride, cholesterol nononoate, and oleyl carbonate.

Incident and reflected signals are recorded. The probe, sensitive to 0.1 C, has no effect on the microwave field. A viscometric probe, based upon the temperature dependence of liquid or gaseous flow through an orifice, is under study by Chen and Cain at the University of Illinois. Also being developed (Univ. of Utah) is a semiconductor probe using internal reflection of laser light from gallium arsenide, expected to be sensitive to changes of about 0.2 C.

Dr. A. Deficis (DERMO) gave a brief history of electromagnetic field detection and measurement and a description of the liquid-probe device in use at DERMO. The probe detects changes in radius of curvature of a liquid meniscus and is uninfluenced by the microwave field. During my visit to DERMO I was shown virtually identical records of the variations of temperature within a resonant cavity with and without the em field.

Research on Biological Effects

The phenomena observed were varied, from observations on growth of plants and microorganisms and the metamorphosis of insects to effects on the central nervous system and behavior of vertebrates. In between there were studies of various vertebrate subsystems *in vivo*: lipid metabolism, and the reticuloendothelial system, and *in vitro*: *plasma coagulation*.

Growth of Yeast: Léo Thourel, Director of DERMO, described experiments by B. Thourel on the growth of yeast subjected to microwave fields over the frequency range 2.0 (0.10) 12.4 GHz. In the course of many experiments there seemed to be frequencies at which subsequent growth, after dilution and plating on nutrient agar, was consistently unaffected, others at which inhibition, and yet others at which stimulation were seen. Talking with B. Thourel in the laboratory, I learned that tubes of cells in aqueous suspension were exposed to the fields inside a waveguide in a configuration calculated to correspond to a matched load. Power densities were not given, but the exposures were terminated when the temperature had risen to 30 C. Control suspensions were subjected to similar increases of temperature. The explanation for these frequency-dependent effects is not yet apparent. No simple relationship was seen between the various frequencies at which positive, or negative, effects were found. Measurements in the Coulter Counter and observations in the scanning electron microscope suggest that the em field may affect the detachment of buds or may produce aggregation analogous perhaps to the chains of red blood cells described by Schwan and others. Such effects may invalidate the assumption that the number of visible colonies on agar is equal to the number of viable cells in the inoculum.

Insect Metamorphosis and Morphogenesis: Professor You-Hing Tchao (Univ. Valenciennes) described experiments done in collaboration with Jean-Jacques Lenoir-Rousseaux (Univ. Paris-Sud, Orsay) on the use of microwaves to block the synthesis of hormones involved in the triggering of insect metamorphosis.

Irradiation of the cephalic region of the coleopterid *Tenebrio molitor* at different stages of pre-nymph development is presumably a more convenient technique than surgical ligation or coagulation. The field densities used are rather high (200 $mW.cm^{-2}$) and the total energy around 1 W.min at 9.300 GHz. The times of irradiation were chosen with reference to three known periods of peak rate of synthesis of α-ecdysone in the prothoracic glands, thought to be controlled by a "brain hormone." The α-ecdysone in turn controls the synthesis of β-ecdysone which is responsible for certain transformations from larva to pre-nymph to nymph. The consequences of irradiation at three different stages in the pre-nymph condition were consistent with blockage of the different phases of α-ecdysone synthesis as deduced from observations of the stage of development attained subsequently. Although Tchao's exposition was very difficult to follow, even for the French listeners, I was impressed by his critical approach to the whole field of microwave effects and his appreciation of the need for matched physical and biological competence in such investigations.

Experiments on malformations in *T. molitor* resulting from irradiation at 2.45 GHz at various stages of development were described by Anglade, Cangardel and Fleurat-Lessard (Station Zoologique, Centre de Recherches de Bordeaux) who attempted by measuring oxygen consumption to correlate these effects with metabolic changes. Some of the metabolic changes initiated by irradiation appeared to persist beyond the actual irradiation period.

Lipid Metabolism: Professor Dumas and S. Laurens (Faculté de Pharmacie de Toulouse), working at DERMO, have found frequency-dependent effects of irradiation upon the lipid metabolism of two strains of mouse. I saw how the irradiation was done. The caged mice were placed in a large anechoic chamber traversed by the waveguide at ceiling level. The frequency range was 2-4 GHz, the energy input was at the rate of 4 W, and the energy density probably in the lower $mW.cm^{-2}$ range. Serum cholesterol, lipoprotein, and triglycerides were measured. The serum triglyceride levels were normal at 2.3 and 2.5 GHz with a pronounced peak at 2.4 GHz. Somewhat similar results were found with both mouse strains, but the investigators were able to distinguish between "indifferent" and "sensitive" animals. There was some discussion of the possibility of standing waves in the mouse with body dimensions comparable to the wavelength (in air). The question of differences in the activity of the animals was also discussed, and the absence of significant weight changes was noted.

Reticuloendothelial System: Draussin (Faculté de Médicine de Nîmes, Nîmes) described experiments by Professor L. Miro, Professor Senelar, Draussin, and Grasset on the effect of exposure of rabbits, guinea pigs, and rats to microwaves upon the fixation and elimination of injected radioactive colloid and on the serum gamma-globulin concentrations. The power densities were very low (1.0-1.5 $mW.cm^{-2}$), the exposures, in a large anechoic chamber, prolonged, and the effects observed rather unimpressive.

Coagulation of Plasma: Dumas and Yazdanian (Faculté de Pharmacie de Toulouse), working at DERMO, have been following the coagulation of plasma when irradiated in presence of the initiating reagents. The tubes of plasma are placed in the microwave cavity while a cephalin-kaolin reagent is added and left for 3 minutes before adding calcium chloride. After 20 seconds the tube is removed and the contents agitated magnetically by a "flea." Formation of the clot is marked by cessation of movement of the flea. This is observed visually and recorded. The data presented showed the normal coagulation time around 57 sec at frequencies 8 and 10 GHz to be increased to about 73 sec at 9.8 GHz. Deficis replied negatively on Dumas' behalf to the speculation that cavity resonance could account for this result. A suggestion, however, that the observed effect could originate with a modification of the reagent rather than the plasma was taken seriously.

Central Nervous System and Behavior: The difficult question of effects on the central nervous system produced by chronic low-level exposure has been considered in much detail by B. Servantie who has indeed reviewed the pitfalls and the results published from his own laboratory and others[12]. His work is being pursued with a team of two coworkers, B. Creton and Mme. J. Obrenovitch, at the naval base in Toulon. They have found significant changes in the electroencephalograms (EEGs) of white rats after 15-day exposure to average field densities around 5 $mW.cm^{-2}$ at the two "standard" frequencies 2.45 and 0.95 GHz, using both continuous and pulsed fields. One interesting observation is that the modulation frequency makes its appearance in the EEG and persists. Frequency-dependent behavioral effects have been found in 115 animals by measuring various indices of activity on a grid within an enclosed space. Calculations of the attenuation of microwaves as a function of depth in different tissues in series between skin and brain show this to be very different for the two frequencies used. This points up the difficulty in determining the actual energy absorbed by different parts of the nervous system and so arriving at any precise idea of the site of observed behavioral effects.

Medical Applications

Microwave Radiometry of Tumors: The attractions offered by microwaves in the field of detection and treatment of cancer have not gone unnoticed. Non-invasive detection based upon the high heat production of tumors may be possible if "hot spots" beneath the body surface can be located. Ordinary radiometry merely measures surface temperature. A. Priou (DERMO) showed that if the frequency is suitably chosen in relation to the black body radiation curve and if the tissue absorption is appropriate, it should be possible to detect "hot spots" under the surface with a microwave antenna (cf. Cheng, *ESN* 30-10:458). Antennas and amplifiers for a radiometer sensitive to 3.3 GHz have been constructed, and practical tests have shown promising correlation between readings and the frequencies of occurrence of "true positives" and "true negatives" among tumors and normal tissues.

Elaborating upon this approach, and reporting the work of A. Mamouni, F. Bliot and Y. Moschetto, Professor Y. Leroy (Univ. Lille) showed that by a combination of infrared thermography (to determine surface temperature) and hyperfrequency radiometry (to detect subcutaneous heat sources) it might be possible to arrive at a three-dimensional temperature chart which would have diagnostic value. Alternatively it might be possible by similar measurements to solve the equations for the components of the complex dielectric constant at the microwave frequency and thus to determine its value *in vivo*. Experiments on liquids at 9 GHz were reported.

Selective Heating of Tumors: For some of the same reasons that might justify the attempt to develop microwave radiometry, application of microwaves might be expected to cause differential heating of tumors if the position and electric properties are favorable. R. Zimmer, with M. Gautherie, D. Gros and Professor Gros (Univ. Louis Pasteur, Strasbourg) investigated this possibility theoretically because of the belief that hyperfrequency radiation augments the sensitivity of cancer cells differentially—by a factor of 4 compared to a factor of 2 for normal cells. An analytic solution was found for the electromagnetic field in a volume of tissue of dielectric constant ε_2 in a tissue medium ε_1, assuming $\varepsilon_1' \sim \varepsilon_2'$ and $\varepsilon_1'' \neq \varepsilon_2''$. Calculation of temperature profiles across a breast tumor is then possible if assumptions as to heat transfer can be introduced realistically. The tissue complex dielectric constant can be measured from the impedance of a dielectric antenna embedded in the medium. Various tests were made by thermofluorography and the hope expressed that differential heating of mammary tumors to 43 C will become possible.

Fixation of Radiotherapeutic Substances by Tumors: A third paper on cancer dealt with the increased fixation of technetium phosphates used in the treatment of bone cancer following microwave treatment. Data presented by Professor Regis with Professor Bru, F. Vigoni, A. Blasco and J. Pradere (Faculté de Médicine de Rangueil/Toulouse) demonstrated the increased fixation following exposure for one hour to a 50-W field at 3 300 MHz, but left open the question whether this was due to a thermally induced increase of bone metabolism or a specific effect. No sensations of heat were reported. A listener asked whether the microwave heating might increase the risk of metastatic migration.

Microwave Thawing of Blood Pellets: As a final quasi-medical topic may be mentioned the paper by Dr. Bouloux (DERMO) on the microwave thawing of blood frozen in pellets. The advantages of rapid thawing are no doubt considerable, but various changes, particularly a decrease in white cell count, should not be ignored in the evaluation of such a procedure.

Industrial Applications

Food Thawing and Food Sterilization: Industrial applications had little place in the symposium, but some are receiving attention at DERMO.

A 915-MHz cavity is being used for food sterilization by heating to 80 C, and an assemblage on an industrial scale is being designed.

Rapid thawing of frozen food is a practical possibility on small and large scales. The set-up at DERMO thaws a side of beef in half an hour. The frequency used in 915 MHz, the power flux 25 kW, and 5000 kg can be processed per day.

COMMENT

Research in France on the biological effects of microwaves is seen to be mostly on an empirical level, with little immediate concern for fundamental mechanisms. At the same time, there is a disciplined desire to ensure the reproducibility of data and a precise statement of the experimental conditions. This is understandable in the aftermath of the "affaire Priore" referred to on page 6, which has been a set-back for research in France on the biological effects of microwaves. The fund-granting agencies became reluctant to provide support, and this in turn generated unhealthy timidity among the scientists interested in the subject. There is in any case a genuine difficulty in finding a valid scientific approach to the Priore claims, as long as the machine continues to emit mixed radiation of unspecified character whose magic properties were apparently stumbled upon by accident. The route followed by the workers who reported at the CERT meeting was the scientifically orthodox one of using one frequency at a time and selecting the simplest possible types of biological response compatible with the level of organization which it was desired to study. If biological actions of microwaves are as frequency-selective as some reports seemed to show, the chance of discovering special enhancements produced by particular mixtures of frequencies, intensities and pulse patterns would be remote indeed if the only method available were one of systematic trial and error. It is understandable that attitudes to Priore's machine are sharply polarized.

Despite the striving for methodological rigor that the French scientists are now obliged to exhibit, I was disappointed to find so little attention given to the reporting of details about the physical equipment used and especially to dosimetry and thermometry. It would have been desirable, in my view, to devote at least a brief introductory session to an overview of the types of oscillator now in use and their output characteristics such as stability of frequency and bandwidth. More should have been said about the methods available for the various measurements needed in order to estimate absorbed energy and possible increases of temperature.

One is left with the recollection of a number of fascinating observations made carefully and laboriously but remaining tantalizingly at the edge of scientific credibility, as though in each case some vital but subtle control factor may have been overlooked.

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APPENDIX I

L'ECOLE NATIONALE SUPERIEURE DE L'AERONAUTIQUE ET DE L'ESPACE

&

LE CENTRE D'ETUDES ET DE RECHERCHES DE TOULOUSE

vous accueilleront les 5 et 6 JUILLET 1977

pour les

JOURNEES D' ETUDES SUR LES EFFETS BIOLOGIQUES DES MICRO - ONDES

placées sous la Présidence de

Monsieur Maurice PONTE

Membre de l' INSTITUT

avec le patronage de

L'INSTITUT NATIONAL DE LA SANTE ET DE LA RECHERCHE MEDICALE

et de

L' ELECTRICITE DE FRANCE

PROGRAMME DEFINITIF

JOURNEE DU 5 JUILLET 1977

MATINEE

9 H - 9 H 30	Réception des participants à l'Ecole Nationale Supérieure de l'Aéronautique et de l'Espace.
9 H 30 - 10 H	Allocution d'ouverture de Monsieur Maurice PONTE, Membre de l'Institut.
10 H - 10 H 15	Allocution de Bienvenue de l'Ingénieur Général Marc PELEGRIN, Directeur de l'E.N.S.A.E. et Administrateur du C.E.R.T.
10 H 15 - 10 H 45	Professeur CZERSKI (N.R.I.M.C. VARSOVIE) "Exposé général sur les effets biologiques des micro-ondes et les seuils de sécurité".
10 H 45 - 11 H	Pause café.
11 H - 11 H 30	T. ROZZELL (U.S. NAVY) "Orientations des recherches sur les effets biologiques aux U.S.A.".
11 H 30 - 12 H	B. SERVANTIE (C.E.R.B. TOULON) "Exposé général sur les travaux effectués en FRANCE"
12 H - 14 H	Repas en commun

APRES - MIDI

14 H · 14 H 20	B. SERVANTIE - J. GILLARD - J. OBRENOVITCH - B. CRETON - G. BERTHARION (C.E.R.B. TOULON) "Sensibilité du système nerveux central des rongeurs de laboratoire à l'action des micro-ondes pour de faibles densités de puissance".
14 h 20 - 14 h 40	Professeur DUMAS - S. LAURENS (Faculté de Pharmacie de TOULOUSE) "Etude comparée des effets des micro-ondes sur le métabolisme lipidique de deux races de souris".
14 H 40 - 15 H	Professeur MIRO - Pr SENELAR - MM. DRAUSSIN - GRASSET (Faculté de Médecine de NIMES) "Effets des micro-ondes sur le système réticulo-histiocytère".
15 H - 15 H 20	P. DESCHAUX (Université Claude Bernard LYON) "Taux palmastiques de testostérone, corticostérone, hormones lutéotrope et adrénocorticotrope chez le rat blanc".
15 H 20 - 15 H 40	MM. ANGLADE - CANGARDEL - FLEURAT LESSARD (I.N.R.A. BORDEAUX) "Observations de malformations et des modifications métaboliques chez les insectes, consécutives à l'exposition aux micro-ondes".
15 H 40 - 16 H	TCHAO YOU HING (Université de VALENCIENNES) "Action des hyperfréquences sur la métamorphose de Tenebrio molitor".
16 H - 16 H 15	Pause café.
16 H 15 - 18 H	TABLE RONDE au sujet des seuils de sécurité pour l'homme et discussions sur les exposés de la journée.

JOURNEE DU 6 JUILLET 1977

MATINEE

9 H - 9 H 20	T. ROZZELL (U.S. NAVY) "Capteurs de température non interférents aux ondes électromagnétiques".
9 H 20 - 9 H 40	A. DEFICIS (C.E.R.T. TOULOUSE) "Sondes microthermomètres diélectriques non interférentes".
9 H 40 - 9 H 55	Professeurs BRU et REGIS - MM. VIGONI F. - BLASCO A. - PRADERE J. (Service de Biophysique de la Faculté de Médecine de RANGUEIL/TOULOUSE) "Modifications de la fixation chez l'homme de produits marqués sous l'action d'une irradiation par micro-ondes : premiers essais concernant les complexes de phosphates technetiés".
9 H 55 - 10 H 15	Professeur DUMAS - M. YAZDANIAN (Faculté de Pharmacie de TOULOUSE) "Etude in vitro de l'effet des micro-ondes sur la coagulation plasmatique".
10 H 15 - 10 H 30	Pause café.
10 H 30 - 10 H 50	Professeur L. THOUREL (C.E.R.T. TOULOUSE) "Essai de synthèse sur les effets des micro-ondes sur les micro-organismes".
10 H 50 - 11 H 10	Docteur BOULOUX (ONERA/CERT - TOULOUSE) "Décongélation des hématies et réchauffage du sang en cours de transfusion, par micro-ondes".
11 H 10 - 11 H 30	Professeur BARTHELEMY (Centre Hospitalier RANGUEIL) "Réchauffage du sang par micro-ondes dans une circulation sanguine extra-corporelle".

11 H 30 - 12 H	TABLE RONDE sur les exposés de la matinée.
12 H - 14 H	Repas en commun.

APRES - MIDI

14 H - 14 H 30	R. ZIMMER - M. GAUTHERIE - D. GROS - Prof. GROS (Université L. Pasteur - STRASBOURG) "Approche théorique d'échauffement sélectif d'épithéliomas mammaires par micro-ondes".
14 H 30 - 15 H	Professeur Y. LEROY (Université de LILLE) "Réalisation d'un radiomètre en bande X pour applications biomédicales".
15 H - 15 H 30	MM. PRIOU et BERGES (C.E.R.T./D.E.R.M.O. TOULOUSE) "Etude et réalisation de radiomètres pour thermographie profonde".
15 H 30 - 15 H 45	Professeur ROBERT - Mr CURIEN (Laboratoire d'Isotope Faculté de NANCY) - Mr GAUTHERIE (Faculté de Médecine de STRASBOURG) "Premières applications de la thermographie micro-ondes en pathologie thyroïdienne et mammaire".
15 H 45 - 16 H	Pause café.
16 H - 17 H	TABLE RONDE sur la thermographie profonde. Compte rendu du Congrès de SAN DIEGO.
	Clôture des Journées.

C.E.R.T.

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APPENDIX II

JOURNEES D'ETUDE SUR LES EFFETS BIOLOGIQUES

DES MICRO - ONDES

5-6 Juillet 1977

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