A BRIEF SURVEY OF LITERATURE RELATING TO THE INFLUENCE OF LOW INTENSITY MICROWAVES ON NERVOUS FUNCTION

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I. INTRODUCTION

Recent reports, emanating for the most part from the Soviet Union, indicate that low intensity microwave radiation may produce deleterious effects in organisms. Insomnia, irritability, loss of memory, fatigue, headache, tremor, hallucinations, autonomic disorders, and disturbed sensory sensitivity are among the many and various symptoms reported by humans who are exposed more or less regularly to microwaves in their working or living environment.

The intensity level of microwave radiation now being used as a safety criterion in the United States is based on the gross dissipation of electromagnetic to thermal energy within the organism. The allowable intensity level prescribed from consideration of the gross thermal mechanism is 10 mw/cm^2, and one western investigator has stated that an intensity tem times this level is "disastrous to man" while intensities ten times lower have "no effect on man."[(1)]

Many Soviet researchers, however, contend that microwaves influence the functioning of organisms by mechanisms other than gross heating. The literature on the subject is far from conclusive, however, and the operation of no particular nonthermal mechanism seems to have been clearly delineated. Nonetheless, the fact remains that some people in the west who work and/or live near broadcasting stations, radar stations, and high-powered electrically driven equipment of various varieties are being exposed more or less continually to radiation which at least some Soviet researchers consider dangerous.

This paper presents a very brief survey of available literature relevant to the influence of low intensity microwaves on nervous function.

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II. RELEVANT LITERATURE

Figure 1 indicates the region of interest.

The present concern is with radiation in the frequency range of about 10^8 to about 10^{11} cps (wavelengths from several meters to several tenths of a centimeter) and with intensity less than about 10 mw/cm^2. Literature outside this region includes several reports which have dealt with the influence of magnetic and electrostatic fields on organisms,[2,3] a paper which describes a nonvisual influence of visible light on neural activity,[4] and a relatively large number of reports dealing with effects of relatively high intensity microwave stimulation.[5]

Table 1 lists the papers which have been found in the defined area of interest and which form the basis of the following discussion. (Complete references are given on p. 12.) Dodge has performed a very useful service for English-speaking investigators interested in this problem. He provides a thorough overview and discussion of the scope of the Soviet literature in the field[5] and also a collection of summaries in English[6] of many of the original research articles. Presman is the leading Soviet researcher in the field, and his review published in 1965[7] provides what appears to be the most definitive available statement of the state of the art including reference to some 200 publications, synopses of the more important experimental results, and a discussion of mechanisms which have been suggested by various investigators to explain their observations. Frey[8] also has presented a valuable review.

BEHAVIORAL DISTURBANCES

These review papers cite many clinical reports of behavioral disturbances associated with exposure to microwave radiation of low or moderate intensities. Many of the observed deficiences can be classified into one of three categories: (1) "Neurasthenic syndrome," (2) "autonomic vagotonic dystonia," and (3) "diencephalic syndrome."[5] Unfortunately, the radiation parameters typically are not controlled or

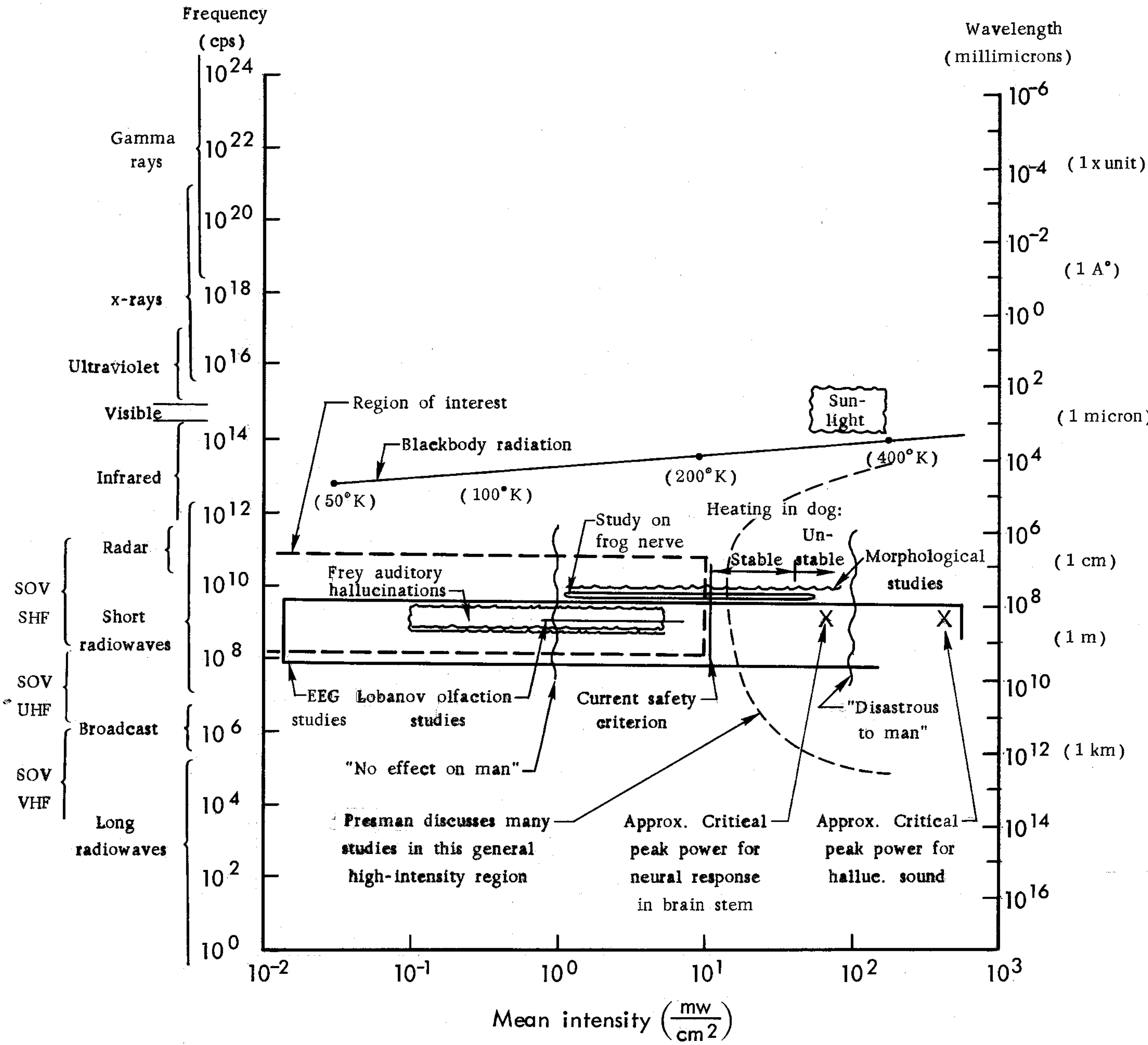

Fig. 1—Map for region of interest

Table 1

SOME PAPERS RELEVANT TO AREA OF INTEREST[a]

Overviews
Presman (65)
Dodge and Kassel (66)
Dodge (65)
Frey (65)

Behavioral	Neuroelectric: Gross Responses	Neuroelectric: Single Cell Responses	Morphological
Lobanov,+ (60)	Kholodov+ (62)	Kamenskiy (64)	Tolgskaya (59)
Frey (63)	Kholodov (63)		Tolgskaya+ (60)
Many papers referenced by Dodge+ (66)	Kholodov (64)		Tolgskaya+ (60)
	Kholodov (66)		Lobanov+ (60)
	Gvozdikova+ (64)		Gordon+ (63)
	Livanov+ (60)		Pervushin (57)
	Baldwin+ (60)		Fukalova (66)
	Frey (67)		

[a]The numbers in Table 1 indicate the year of publication.
+Indicates coauthors.

reported; often neither the frequency nor the intensity level is reported. Nonetheless, the reports are numerous and, according to Dodge,[5] Drogichina,[9] et al. report all three classes of symptoms in personnel subjected to microwave fields of "a few mw/cm^2" intensity and Fukalova[10] reports a "threshold irritant" to be as low as .01 to .25 mw/cm^2.

Moreover, two well-controlled investigations would seem to establish that low intensity microwaves can and do influence sensory processes. Lobanov and Gordon found lower olfactory sensitivities among 358 workers exposed to microwaves than among members of a control group.[11] Among experimental subjects exposed continuously to power densities up to 1 mw/cm^2, the lowest sensitivity was in those exposed less than a year or more than 6 years; among subjects exposed periodically to power densities up to several mw/cm^2 the sensitivity decreased with increased exposure time.

Frey has used microwaves to induce hallucinatory sounds in subjects.[8,12] Buzzing, ticking, hissing, or knocking sounds are repeatedly reported by humans exposed to mean power densities as low as 0.1 mw/cm^2. Frey emphasizes that the peak power density is a more critical measure than mean power density. The peak power threshold for the hallucinatory sound is about 250 mw/cm^2, but depends upon the wavelength and temporal pattern of stimulation. Frey has performed experiments which show that the effect is not mediated through the eyes, ears, or teeth but can be blocked by shielding a small area of the cerebral cortex just above the temporal lobe.

NEUROELECTRIC RESPONSES

Frey[13] has recently decried the general lack of experimentation concerning the influence of microwaves on neuroelectric events. Frey has shown that evoked responses in the brain stem of the cat could be obtained with microwave intensities as low as 30 mw/cm^2 average and 60 mw/cm^2 peak.

Several independent investigators have reported that microwave stimulation produces alterations in the electroencephalogram (EEG).[2,14-19] Stimulation is often followed by increased amplitude and decreased frequency of EEG components, or by decreased amplitude and increased frequency. The general character of the observed EEG alterations is constant throughout a wide range of intensity (.02 mw/cm^2 to $\sim$ 100 mw/cm^2). In general, the percentage of cases evidencing alterations increases with increasing intensity. However, one investigator revealed a larger percent of responses at .02 mw/cm^2 than at intermediate intensities.

The EEG responses show a substantial delay which decreases with radiation intensity from about 100 sec at .02 mw/cm^2 to about 20 sec at 10 mw/cm^2.

The reports of Kholodov[2,14-16] and of Gvozdikova[17] seem the best controlled of those listed in Table 1. The experiments of Gvozdikova utilize intensity levels well into the range of current interest (.02, .08, .4, 2, 10, and 50 mw/cm^2). Most of Kholodov's experimentation involves intensities of the order of 100 mw/cm^2, but he also alludes[2] to results he has obtained with intensity levels of 2 to 50 mw/cm^2.

It is of interest that the EEG alterations observed by Livanov[18] et al. were discovered by accident in an experiment designed for another purpose. The source of the radiation in this case was determined to be a power cable supplying an x-ray source. The parameters of radiation were not determined in this investigation.

Most of the EEG alterations have been observed in rabbits but comparable observations have been reported in monkeys.[19] Kholodov and Livanov, et al. have shown that the observed responses are unaltered when visual, auditory, and olfactory channels are blocked, and Kholodov has observed comparable neuroelectric changes in a strip of cortex isolated by cutting from surrounding tissue.

Kamenskiy[20] has investigated the influence of microwave radiation on a different class of neuroelectric activity. He has subjected a frog nerve fiber tract to microwave radiation while recording the gross electrical response in the tract to applied electrical stimulation. Using both continuous and pulsed microwave radiation with mean intensity 1 to 11 mw/cm^2, Kamenskiy reports that exposure to radiation is followed by increased conduction speed, decrease in refractoriness, and changes in action current amplitude. A change in threshold was found only for pulsed radiation and only for pulse rates of greater than 700 pulses per sec.

MORPHOLOGICAL DISTURBANCES

In a series of studies Tolgskaya and her collaborators have investigated the influence of low intensity pulsed and continous microwave radiation on the morphology of animal cells[21-25] These investigations have repeatedly shown protoplasmic swelling and distension of nerve cells at intensities as low as 1 mw/cm^2. The authors report that nerve cells exhibit swelling at lower intensity levels than those required to produce comparable disturbances in other types of tissue. Dendrites are reported to exhibit a particularly high sensitivity to the radiation; as the number of exposures is increased the deformation extends progressively closer to the nerve cell soma. Pulsed fields produce more pronounced swellings than do continuous fields. Cells in the thalamus and hypothalamus, and apical dendrites of the cerbral cortex are remarked by these authors to be particularly sensitive to microwave radiation. They report further that at low intensities the swelling tends to be more marked for lower frequencies (wavelength greater than about 10 cm). These experiments were performed on rats and rabbits.

According to Frey,(8) Pervushin(26) had earlier reported similar effects in afferent nerve cells of cats. Using intensity levels of 0.5 to 10 mw/cm^2, and 30 mw/cm^2, he reported particular sensitivity in preterminal sections of the afferent cells and in mylinated fibers; the nonmylinated fibers seemed to be unaffected.

Fukalova(10) also found that an intensity of 2 to 3 mw/cm^2 was sufficient to produce swelling of neural fibers.

III. DISCUSSION AND CONCLUSIONS

The primary conclusions to be drawn from this brief survey are: first, it seems likely that neural function, and therefore behavior, are indeed disturbed by low intensity microwaves; and second, the disruption of transport processes across neural membrane is one likely mechanism whereby such a disturbance could be mediated.

The behavioral studies for the most part leave much to be desired in the way of experimental control and clearly specified qualitative results. Nonetheless, the studies consistently and repeatedly report that human beings do exhibit behavioral disturbances when subjected to low intensity microwaves. Moreover, there seems little reason to question the specific investigations of Frey or of Gordon, et al. Considered as a whole, these investigations suggest that microwaves may exert a general and diffuse influence on neural function.

The neuroelectric studies also are consistent with a diffuse and nonspecific influence and are not sufficiently refined to provide much insight into underlying physical events. The morphological investigations on the other hand are extremely important for they provide a singular and clear-cut guideline as to the mechanisms whereby influences might be effected.

Table 2 contains a list of the mechanisms I have been able to think of a priori whereby electromagnetic fields could influence neural activity. No doubt other candidate mechanisms could be added.

It seems quite plausible that microwaves might influence behavior through several mechanisms simultaneously. On the other hand, it should be noted that the distension and swelling of nerve cells is in itself sufficient in principle to account for all the reported anomalies surveyed here. Merely changing the size of a nerve process changes such properties as conduction speed, response amplitude, length constant (for spatial decrement of graded electrical signals) and so on.[29] Any and all of these factors can in theory seriously disturb neural information processing.[30-32] Furthermore, the observed distensions probably reflect and/or are accompanied by changes in electrolyte concentrations which may be responsible for an even more marked disruption

Table 2

SOME POSSIBLE MECHANISMS OF LOW-INTENSITY MICROWAVE INFLUENCE ON NEURAL FUNCTION

A. There is no effect.

B. Direct effects (primary effect on apparatus for neuroelectric ionic fluxes).

   1. Direct influence on ionic currents leading in turn to influence on transmembrane potentials in nerve cells.[a]

   2. Localized heating

      a. change membrane properties, thereby disrupt transport processes,

      b. induce convection currents, thereby disrupt transport processes,

      c. affect processes of synaptic transmission,

      d. affect processes of excitable membrane.

   3. Chemical or structural change in components of membrane, or in apparatus of synaptic mechanisms or of excitable membrane.

C. Indirect effects.

   1. Primary effect on cell metabolism

      a. alter by heating or by structural change properties of membrane thereby disrupting nutritional transfer,

      b. cause structural change in an enzyme or any critical molecule at any stage of metabolic cycle,

      c. alter by localized heating processes of metabolism at any critical stage.

   2. Primary effect reflects "stress"

      a. neural response to disruption of any neuroendocrine control system,

      b. neural response to disruption of any physiological process,

      c. neural sensory response to field directly or to localized temperature disturbances.

D. Disruption by any physical mechanism of hypothetical glial or electromagnetic organic control systems.[b]

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[a]This candidate mechanism is the subject of Ref. 33.

[b]It has been suggested from time to time that glial cells might serve to modulate or control the electrical activity of nerve cells (c.f. Ref. 26), and Presman[(28)] has presented the unsubstantiated hypothesis that electromagnetic fields represent a primary substrate of organism self-control.

of neuroelectric events, or by disruptions in the cell's metabolic apparatus, the functional integrity of which is clearly necessary for normal activity.

One can construct then the tentative hypothetical scheme that (low intensity) microwave radiation somehow induces swelling and distension of neural processes diffusely throughout the radiated region, more or less concentrated in particular regions corresponding to the field intensity distribution. Such widespread swelling would bring about a general and diffuse disturbance of function, the ramifications of which can hardly be delimited. Suffice it to say that such swelling (and what it might reflect) could very easily and naturally be expected to be associated with the diffuse, nonspecific character of the reported behavioral and neuroelectric disturbances.

If the fundamental mechanism does act primarily on membrane transport processes, it is easy to speculate that dendritic and preterminal regions are particularly sensitive because they exhibit larger surface-area to volume ratios than do cell bodies.

It would seem then that the claim that microwaves at intensities of about 1 mw/cm^2 have essentially no effect on man is premature. A basic criterion by which a candidate mechanism could be evaluated, at least in the initial stages of theoretical work, is whether or not it could be shown to produce swelling of neural processes. Among those candidate mechanisms which might be first considered should be: neuroelectric processes and/or general membrane transport processes are sensitive to direct heating from gross dissipation of field energy; ionic fluxes are either driven directly through neural membrane and/or bring about changes in localized ionic concentrations which in turn influence on-going transmembrane transport; membrane permeabilities are altered by "micro heating" or structural change in membrane components and thereby transport processes are altered; structural change occurs in any of many proteins acting as enzymes in metabolic processes, in chemical processes of synaptic transmission, or in processes of excitable membrane, disturbing the normal functioning of the process and eventually resulting in pathological distribution of material.

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