1. INTRODUCTION

Recently, a new category of patients has been described in the literature (cf. Refs. 1 and 2), namely those who claim to suffer from subjective and objective skin- and mucosa-related symptoms, such as itch, smarting, pain, heat sensation, redness, papules, pustles, etc., after exposure to visual display terminals (VDTs) as well as other electromagnetic devices, both at their work and in their home. Some patients also have symptoms from internal organ systems, such as the heart and the central nervous system. Clinical dermatologists often describe these patients as suffering from either some kind of earlier acknowledged skin disease, e.g. seborrhoic keratosis or rosacea, or from so-called 'techno-stress', a term first used in Japan for work-related stress. Also Pavlovian-type conditioning has been attributed to this group of patients. So far, however, very little is known about the exact cause of the above-mentioned symptoms and, thus, generally very little treatment can be offered.

2. AIM and MATERIALS & METHODS

The aim of the on-going study is to investigate possible changes, in the cellular and neuronal systems of the patients' skin, after provocations with electric and/or magnetic VDT-fields. As controls, age- and sex-matched persons working with VDTs (however, without any subjective or clinical symptoms) will serve. Immunohistochemistry using antisera to the previously characterized marker substances of interest in this specific patient category is utilized (cf. Refs. 3-6).

3. RESULTS & DISCUSSION

Initially, we have done the following:

a) Investigated the presence of intraepidermal nerve fibers in normal human skin from healthy volunteers (n = 66) using the new marker protein gene product (PGP) 9.5. The intraepidermal nerve fibers are varicose or smooth with different diameters, running as single processes or branched, straight or bent, projecting in various directions and terminating in the stratum basale, spinosum or granulosum. They are found as close as 20-40 μm from the surface of the viable skin (7), which makes it highly possible that weak electromagnetic fields may affect them. They have also been further characterized using conventional electron microscopy and ultrastructural immunocytochemistry (8), as well as the nerve densities have been calculated for different body regions (9). In addition, a general and profound innervation of the dermis, including the different accessory structures, such as Meissner's corpuscles, hair follicles, arrector pili muscles, around the eccrine and apocrine sweat glands and around certain blood vessels, is also observed (7). Finally, numerous weakly-to-strongly PGP 9.5 immunoreactive cells are found both in the epidermis and in the dermis (7).

b) Performed a 'pilot'-study to elucidate possible changes in certain cellular (immunologic, connective tissue, etc.) markers, as well as in sensory and autonomic nerve fibers. From the preliminary data, it seems plausible to conclude

that the patients (n = 9) differ from both healthy controls (n = 3) as well as from rosacea patients (n = 2), however, further control experiments are needed.

c) Studied, in an open-field situation, the effect of electro-magnetic fields (EMFs) from an ordinary TV set (duration: 30, 60 or 210 minutes; distance 50 cm) on the cellular/neuronal populations of the skin of sampled patients (n = 2). In the biopsies taken before provocation, a remarkably high number of somatostatin immunoreactive dendritic cells was found in the dermis, preferentially around the blood vessels and hair follicles as well as in the basal layer of the epidermis. Furthermore, a profound amount of histamine positive mast cells could be detected before the start of the provocation. After provocation, no somatostatin immunoreactive cells at all could be revealed in the patients investigated using the presently employed immunohistochemical method. Regarding the histamine cells, no changes in morphology, number or fluorescence intensity were observed after the provocation, as compared to the pre-provocation state. There were no differences in the substance P, calcitonin gene-related peptide, neurokinin A, galanin, vasoactive intestinal polypeptide, peptide histidine isoleucine amide, neuropeptide tyrosine, methionine-enkephalin, dynorphin, protein S-100, neuron-specific enolase or PGP 9.5 immunoreactivities before and after the provocation, and the patterns generally looked normal. From these studies, it is evident that certain paramount and profound changes in the dermis and epidermis take place, however, the material still is very small (10).

d) Investigated the presence of mast cells in skin from patients using histamine-based immunohistochemistry (11, 12). From these studies (13; cf. Fig. 1), it

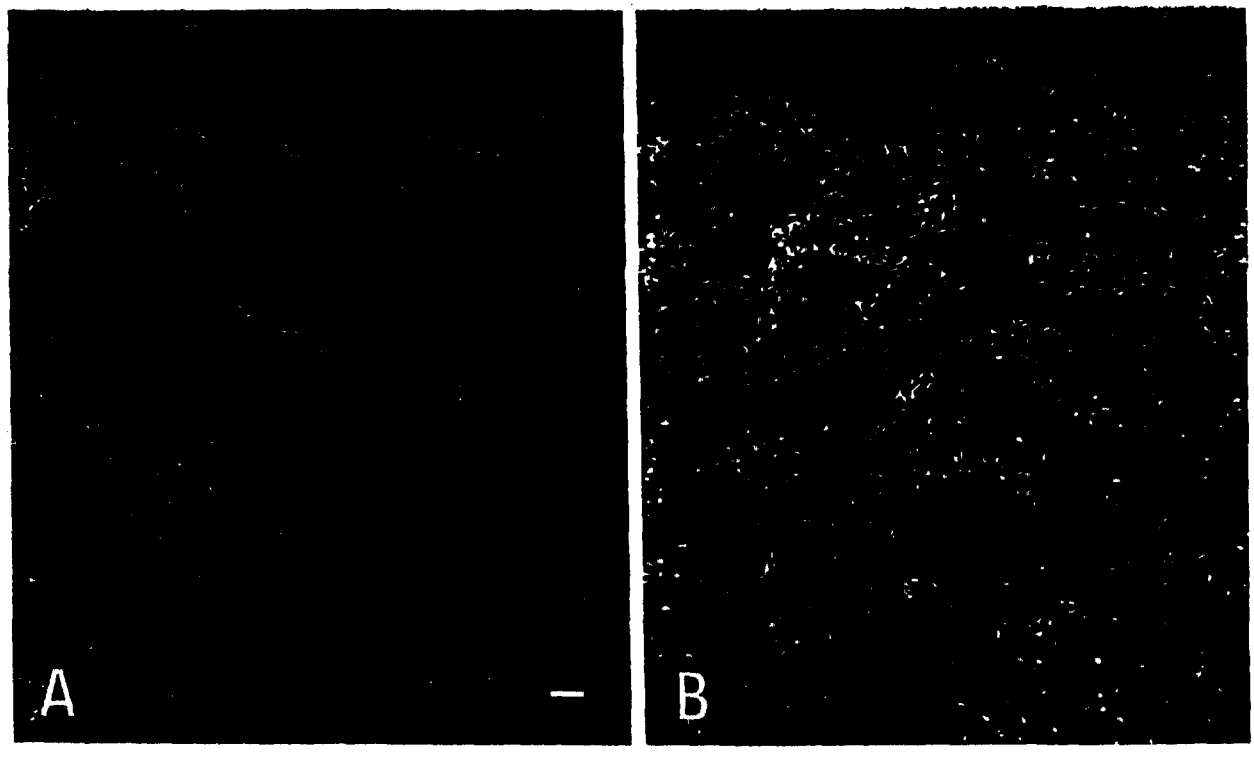

Fig. 1. Immunofluorescence micrographs using histamine antiserum of skin from a normal healthy volunteer (A) and from a screen dermatitis patient (B). Please, note the large difference in distribution and number of the immunoreactive cells. Bar indicates 100 μm.

is clear that the number of mast cells in the upper dermis is increased in the screen dermatitis patients (n = 15) as compared to normal healthy skin (n = 15). A different pattern of mast cell distribution also occurs in the patient group, namely, the normally empty zone between the dermo-epidermal junction and mid-to-upper dermis has disappeared in the patient group and, instead, this zone has a high density of mast cell infiltration. Finally, in the patient group, the cytoplasmic granules are more densely distributed and more strongly stained than in the control group, and, generally, the size of the infiltrating mast cells is found to be larger in the patient group as well (13).

e) Started to investigate possible stimulus-response couplings, during blind provocations (duration: 60 minutes; distance 30-50 cm) with electric and/or magnetic fields using verbal descriptors (n = 7). The study is in an on-going phase, and therefore only preliminary observations have been made. However, in summary, it is already obvious that several background milieu factors may interfere in such provocation studies.

4. SUMMARY

In summary, it is evident from our preliminary data that major biological changes may be present in the patients suffering from EMF exposure. In view of the recent epidemiological studies pointing to a correlation between long-term exposures from magnetic fields and cancer (14, 15), our data ought to be further analyzed.

5. ACKNOWLEDGEMENTS

Supported by the Swedish Work Environment Fund (proj. no. 93-0344 and 94-0375), Nokia Monitors, Sun Microsystems AB, Radians Innova AB, Sun-Flex Datamiljö AB, Käro-Produkter AB, Magn. Bergvalls Stiftelse, funds from the Karolinska Institute, and the generous support of private donors. For a generous supply of antisera we are grateful to Drs. A. C. Cuello, Montreal, D. Dahl, Boston, R. P. Elde, Minneapolis, J. Fahrenkrug, Copenhagen, K. Haglid, Göteborg, L. Olson, Stockholm, L. Terenius, Stockholm, and E. Theodorsson-Norheim, Stockholm, respectively. Ms Shan-Ying Liu, Ms Gunilla Holmkvist and Ms Eva-Karin Johansson are gratefully acknowledged for their expert technical and secretarial assistance, respectively.

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11/25/97

TO: Secretary of the Federal Communications Commission
1919 M St. NW
#222
Washington DC 20554

RE: Complaint of Discrimination on the Basis of Handicap filed by the Cellular Phone Taskforce on February 2, 1997
Disabilities issues taskforce and ET Docket #93-62

Dear Mr. Secretary:

Enclosed is additional documentation in support of the appeal of the Cellular Phone Taskforce referenced above and filed on October 6, 1997.

Sincerely,

Lucinda Grant

Lucinda Grant
Member of the Cellular Phone Taskforce

PO Box 4146
Prescott AZ 86302
Phone: 520-778-4637

USDoc.

Biological Effects & Health Implications of Microwave Radiation
Stephen F. Cleary, ed.

REVIEW OF STUDIES OF PEOPLE OCCUPATIONALLY EXPOSED TO RADIO-FREQUENCY RADIATIONS[1]

JANET HEALER

Allied Research Associates, Inc., Virginia Road, Concord, Massachusetts

There is increasing evidence that radio-frequency radiations can affect biological organisms, even at relatively low intensities, particularly under conditions of chronic exposure. A substantial number of observations have been made at intensity levels below those presently accepted as tolerable for continuous exposure in the United States and most of Western Europe.[2] To date, the deleterious effect of radio-frequency fields, particularly of microwaves, at relatively high intensities, e.g., 50 mW/cm^2 or greater, has been recognized and attributed to heating. However, biological hazards may exist at lower levels, extending well below 10 mW/cm^2, and effects at both high and low intensities may be attributable to more complex modes of interaction. At low intensities effects may be subtle, impairing performance; chronic, affecting general mental and physical health and longevity; and may also be mutagenic, affecting succeeding generations. In addition, any biological damage occurring coincident with radio-frequency exposure can lead to medical-legal problems which would be difficult, if not impossible, to adjudicate on the basis of present knowledge.

Direct data on human response is almost exclusively derived from clinical studies of occupationally exposed workers. These occupational exposures encompass various frequency regions and are characteristically of relatively low intensity. Supplementary data have been derived from collateral animal experiments and an occasional human experiment. Animal data are indirect, with problems of extrapolation.

Almost all of the large-scale, long-term clinical investigations of exposed people and, therefore, information in this area, comes from the Soviet Union and Eastern European countries. In these countries, a great deal of emphasis is placed on occupational health and industrial hygiene. Many institutes and their affiliated clinics have participated in studies of the effects and potential hazards of r. f. radiations.

In the Soviet Union, recognition of subjective complaints, symptoms, and cases of impaired performance of exposed workers, led to a focus on research at low radiation intensities. By contrast, in the United States primary concern has been with the thermal hazard of these radiations and consequently with studies at considerably higher intensity levels (see, e.g., 85, 86, 88, 105). Few studies of exposed populations have been conducted in the United States and this class of effects (the so-called "clinical syndrome") is not generally recognized or accepted as attributable to r. f. radiations; particularly, not at the low intensities reported in Soviet studies (<10 mW/cm^2).

There has been considerable controversy and skepticism in the West about the health hazard of prolonged low-intensity exposures and the validity of the foreign observations. There are several reasons for this. The complaints of occupationally exposed workers are primarily amorphous and neurasthenic, and nonspecific in that they can be produced by stresses other than radio waves.

At least in the early stages, reported symptoms are mild and generally not sufficient to cause an individual to seek medical attention or to be disabling, even through alertness and efficiency may be impaired. For the most part, disturbances lie within clinical norms or tolerances.

In most cases, symptoms are functional and are not accompanied by severe pathological changes. Typically, they disappear when the individual is removed from the exposure environment, with occasional reports of exceptions involving individuals showing very pronounced symptoms, usually re-

[1] This paper is based in part on material compiled with the support of U.S. Army Medical Research and Development Command Dept. of the Army.

[2] Ten milliwatts/square centimeter.

[1] The term "biol ... ical changes ... nd does not c ... clinical signi...

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US Dept. of HEW, Pub. Health Serv., Rockville MD

sulting from long-term exposures and/or intensity levels above those permissible under Soviet standards (e.g., 10 $\mu W/cm^2$) (20, 21, 23, 81, 84, 95).

Additional uncertainty stems from difficulties in measuring some of the extremely low-intensity levels reported (e.g., microwatts/cm^2) particularly under nonexperimental conditions (e.g., people often move about in facilities where objects and various configurations of the surroundings can produce reflections and standing waves).

Some confusion has ensued from the classification of effects as "thermal" or "nonthermal," presumably (and perhaps prematurely and erroneously) according to causative mechanism. The lack of a proven biologically significant mechanism for "nonthermal" interaction became another basis for skepticism over the existence of effects at very low-intensity levels.

Furthermore, differences in investigating and reporting methods and the lack of ready access to details of foreign experiments have compounded our difficulties in interpreting, evaluating, and reproducing experiments and results. As reported, the studies vary in quality with respect to statistical methodology, use of controls, dosimetry, preexisting health status, and attention to other environmental factors. However, some studies are quite attentive to these considerations. While it is difficult to assess the statistical methodology in detail from these reports, standard statistical methods such as the Student t test for level of significance are frequency used.

Efforts are being made to elevate the level of technological sophistication of controls and measurements for the collection of quantitative and definitive data (36, 39, 64, 72, 90). For example, with respect to dosimetry, the Leningrad Institute of Labor Protection has been concerned with the development of precise instrumentation and standardization for field measurements (55). Two widely used field measurement devices: one for the microwave range (PO-1-MEDIK) and one for lower frequencies (IEMP-1) are described in the literature (28, 39, 55, 67).

Even allowing for a substantial error in dosimetry, there is evidence of biological effects[3] in response to chronic low-intensity exposures. In many cases, those indices which appear affected by r. f. exposures in clinical examinations of humans have been investigated in more controllable laboratory experiments with animals which have produced supporting data.

Furthermore, the existence of effects can be established independent of questions of clinical significance, hazards, or even of mechanisms. The full clinical significance and the hazard potential of the effects (individually and collectively) are not fully understood and require further assessment. Nonetheless, these effects are indicative of a disturbance of normal condition and a process of change. As such, they should not be dismissed prematurely.

There has been a steady expansion of research at low intensities in the Soviet Union in the directions of both larger-scale and longer-term clinical studies of people and more elaborate animal experiments. A number of extensive clinical studies have been conducted over a period of 20 years at various Soviet and Eastern European Institutes (39, 43, 49, 59, 60, 67, 70, 71, 81, 100, 101, 108). The Institutes of Labor Hygiene and Occupational Diseases in Moscow and Leningrad have been particularly active in this area. The Gorky Institute has done work with emphasis on lower frequencies. Institutes in Czechoslovakia and in Poland are also active in this area. As an example, the Moscow Institute conducted a 10-year study of over 1000 individuals exposed in various occupations over periods from months to as long as 20 years (20, 39, 59, 94). The study included investigation of symptoms associated with chronic, long-term low-level exposures that "do not produce a thermal effect." Effects of various frequency bands were compared from below the high-frequency (HF) band up through the superhigh frequency (SHF) band. A large portion of the work was done in the centimeter range with reported exposure intensities of 1 mW/cm^2 and below. Even at these low intensities, systematic, long-term exposures were reported to produce symptoms. Similar observations have been made at these and lower frequencies extending into the ELF region. (For example: VHF (30, 31, 35, 70, 81), HF (30, 31, 45, 70, 81), MF (50, 81), LF (81, 101), and ELF (4, 45).

It is also of interest that in Soviet studies of people occupationally exposed to pulsed and static mag-

[3] The term "biological effects" is used in this paper to refer to biological changes or shifts associated with conditions of irradiation and does not contain any necessary or inherent implication of either clinical significance or hazard value.

netic fields of hundreds to a few thousand oersteds, symptoms were observed similar to those produced by r. f. exposures and maximum permissible exposure levels were proposed (111–113).

In the United States, only isolated studies of this nature exist, such as those of Barron (6) and Daily (18), and the ocular studies of Cleary (16, 17) and Zaret (117). For example, Barron et al. (6) in the 1950's examined 226 radar workers grouped by years of exposure and by two intensity ranges (below approximately 13 mW/cm^2). They conducted follow-up studies on approximately 100 individuals 6–9 months later. Their primary finding was changes in blood composition, most notably in the leukocytes. Also mentioned were occasional complaints of headache, fatigue, aching eyes, and occasional cases of sound and warmth sensations under some conditions.

In the Russian literature, reference is made to the "stereotype-nature" of complaints and to the "pattern" of complaints of radio-frequency exposed workers. It is interesting that as early as 1933, a report referring to two workers exposed to r. f. fields refers to their having "complaints which are common to that occupation" (97). Several Soviet investigators comment on the stimulating effect of early observations of subjective complaints on subsequent research programs. For example, Obrosov (79) states that early awareness of the symptomatology led to a formal request being submitted to the State Institute of Physiotherapy in 1942 to investigate the complaints of radar workers, which, in turn, led to investigations of therapeutic applications.

The symptomatology associated, in the Soviet literature, with prolonged exposure most commonly includes headache, increased fatiguability, diminished intellectual capabilities, dullness, partial loss of memory, decreased sexual ability, irritability, sleepiness and insomnia, emotional instability, sweating, and hypotension. Shortness of breath (dyspnea) and pains in the chest region are also reported. Symptoms of disturbance of the vegetative nervous system including sinus arrhythmias, a tendency toward bradycardia, and other vagotonic changes are common observations. There appears to be a certain commonality and consistency to the symptomatology for exposures in the various frequency bands, although some distinctions have been suggested (37, 38, 59, 81). Various Soviet investigators have grouped symptoms into clinical syndromes which vary in number and terminology, but are essentially similar (22, 23, 84). For example, based primarily on data from the centimeter range, investigators at the Moscow Institute of Labor Hygiene define 5 specific syndromes related to the stages of the condition (22, 23). (Mild exposures result in the "vegetative" and "asthenovegetative" syndrome; and in the acute stage, the "angiodystonic" and "diencephalic" syndromes are described.) The two more severe syndromes include symptoms described as emotional instability, weakened memory, cardiovascular problems, severe seizure-like headaches, fear, and shivering. At this stage, the condition is described as disabling, requiring removal from work and hospitalization. These more severe conditions are not frequently seen.

The most commonly reported objective physiological changes are neural, cardiovascular, blood compositions, and endocrine functions. Objective measurements carry more weight than subjective symptoms, and some attempts have been made to correlate the rather amorphous symptoms of the "clinical syndrome" with objective measurements such as electroencephalography. Although time will not permit detailed discussion of individual studies, certain general results can be noted.

Nervous system effects, to be discussed in some detail tomorrow, will only be briefly mentioned here. These effects are prominent among reported observations. A substantial body of data (human and animal) indicates that the nervous system (particularly the central nervous system) reacts to intensities of radiation below the threshold of response of other body systems and reacts sooner (37, 38, 40, 48, 51, 52, 87, 92). There is a majority opinion among Soviet investigators that of all body systems, the nervous system is most sensitive to these radiations. The emphasis placed on the prominent role of the nervous system in these reactions is consistent with the Soviet view and reflects the influence of Pavlovian teaching.

At low intensities, neural changes, like other reported biological shifts, are typically functional, are not accompanied by distinct pathological change, and disappear after the subject is removed from the radiation environment. Nervous system response is expressed in the electroencephalogram (EEG) and by altered response times. Commonly, responses are characterized by initial excitation followed by subsequent inhibition. Other reported

changes include threshold shifts generally in the direction of increasing thresholds for sensory perception, increases in the latent period of the conditioned-reflex reaction, and disruption of vegetative system regulatory and compensatory functions.

Various biochemical, neurohumoral and metabolic disruptions have been observed which can affect neural and other body functions (7, 13, 38, 119). Changes in histamine in the blood (generally increases) have been reported (22, 23, 32, 33). Decreased cholinesterase levels are frequently reported in exposed people and also in animals where they have been observed in connection with altered neural response (13, 31, 38, 74, 75, 102, 106).

EEG changes have been observed in some occupationally exposed people at microwave and lower frequencies (12, 21, 24, 25, 27, 34, 45, 52, 109, 114). These changes are reported to be early occurring and often appear before other changes are detectable in the organisms. They are frequently reported to persist after the cessation of irradiation. The changes are generally polymorphous, and are not necessarily unique as they can be observed in response to other factors.

In general, reported effects in the EEG are characterized by predominance of the slow rhythms (alpha and theta rhythms). Most frequently, changes occur in the amplitude characteristics of both fast and slow waves. Paroxysmal bioelectric activity is reported such as spasmodic spike-type discharges, etc. This activity is noted most often during sensory stimulation. In more severe cases, more pronounced epileptiform bioelectric activity may also be observed.

A Czechoslovakian study of persons exposed to cm wave radiations reported finding certain correlations between EEG activity and other clinical observations and subjective complaints (52). The investigators feel that this indicator can point toward more serious changes than were ascertainable from clinical evidence only, and that the observed EEG activity was useful in further localizing the disruptions which, they feel, are mesodiencephalic. They regard EEG shifts as a kind of early-warning system for detection of organism response to r. f. radiation on a very subtle level.

Similar observations were made at 500–2400 Hz, 3.5 MHz, and with occupational magnetic-field exposures (45, 112, 113).

EEG reactions (with rhythmic light stimulation and hyperventilation) were studied in individuals occupationally exposed to centimeter and lower frequency radiations who showed various degrees of the "clinical syndrome" (34). Individuals were grouped by length of service, which extended up to 20 years. Disturbances were observable in the slow rhythms. The degree of manifestation appeared related to the degree of the clinical syndrome. Radiations in the VHF/HF range were reported as more effective in producing shifts than those in the SHF/UHF region. The EEG was one of the factors used by this group in their categorization of specific syndromes (22).

Changes in the function of the visual, auditory and olfactory modalities have been reported in man and in experimental animals, under a variety of irradiation conditions, including low-exposure densities ($\ll$10 mW/cm^2) (9, 11, 14, 29, 62, 68, 102). Functional changes in sensory systems and conditional reflex behavior at these intensity levels have been found to be accompanied by slight and reversible histological disruptions in the receptor apparatus in some animal studies (60, 106, 107). Olfactory and auditory perception disturbances generally take the form of a depressed reaction or response, increased thresholds and increased latent period of response to stimuli. There are reports of alterations in pain sensitivity in the direction of increasing the threshold (reduced sensitivity), (20, 49) and indications of stimulation of cutaneous thermoreceptors (47) by extremely low-intensity radiations. In one study, the administration of caffeine was found to temporarily increase the depressed olfactory sensitivity leading the investigator to implicate functional shifts in the cortical portion of the olfactory analyzer (29).

A U.S. study of auditory thresholds at intensities of 0.5 mW/cm^2, 1.0 mW/cm^2, and 1.5 mW/cm^2, exposed people with normal hearing to CW (1000 MHz) radiation with and without sinewave modulation (at 400 and 1000 Hz) for two minutes prior to and during presentation of various auditory stimuli (11). A significant decrease in auditory thresholds was reported for 5000 Hz auditory stimulation which was proportional to the magnitude of the average power density. Also, the thresholds were significantly lower with 1000 Hz than with 400 Hz modulated radiation. This increased sensitivity is interesting in contrast to the decreased sensitivity reported by Soviet investigators in subjects who had experienced long-term exposures. It would be interesting to see whether this effect

would persist under chronic exposure conditions or eventually shift in the opposite direction.

Numerous Soviet studies cite cardiovascular disturbances which they widely regard as the predominant vegetative response to radio-frequency irradiation (19, 20, 26, 40, 54, 74, 78, 80, 81, 83, 95, 110). In general, cardiovascular responses are characterized by hypotension, dystonia, and vagotonic reactions. Electrocardiographic (EKG) studies of exposed people and of animals, report a predominance of bradycardia, arrhythmia, and particularly sinus arrhythmias. Depressed intracardial conduction, commonly intraventricular, and lowered EKG waves, particularly T-waves, are also reported. Shifts are reported more often in persons with long histories of occupational exposure. Some examinations suggest a heightened susceptibility of persons with predisposition to, or a history of, cardiovascular disease. In the interest of occupational hygiene, many Soviet investigators (and at least one U.S. researcher) have recommended that cardiovascular abnormalities be used as screening criteria to exclude people from occupations involving radio-frequency exposures (1, 69, 80, 110).

An extensive examination program was conducted by the Institute of Labor Hygiene and Occupational Diseases, Moscow, involving over 500 individuals, periodically exposed for periods up to approximately 10 years to cm and longer wave radiations at low intensities (e.g., below 1 mW/cm^2, and up to several mW/cm^2) (20, 23, 54, 74, 80, 93, 95). This program revealed a variety of cardiovascular shifts predominant among which were bradycardia and vascular hypotension. Differences in responses to acute exposures of higher intensities and longer term chronic exposures at lower intensities were noted. Although these effects are generally reported to be reversible, a few exceptions are noted for certain individuals chronically exposed over many years, who showed pronounced pathological conditions (20, 21, 23, 95).

In the blood, alterations have been reported in the protein fractions, ions, histamine content, hormone and enzyme levels, and immunity factors, but most frequently reported are changes in cellular composition (5, 7, 13, 15, 22, 23, 32, 33, 42, 56, 65, 81, 103, 105, 116). These changes are somewhat variable, but are most commonly characterized by instability of leukocyte indices. Leukocytosis is often seen and leukopenia also occurs, sometimes preceding a shift to leukocytosis. Leukocytosis may vary in type; e.g., monocytosis, lymphocytosis, and eosinophilia. Cases of shifts in other formed elements also have been reported, including reticulocytosis and thrombocytopenia. Changes in erythrocytes and hemoglobin concentration are less frequently reported. These shifts often lie within clinical tolerances, and are a common response to various physiological stressors. They do, however, indicate a reaction to r. f. radiation.

Increased thyroid gland activity and sometimes enlargement is the most commonly reported endocrine response of exposed people (19, 21, 23, 81, 93, 99, 119). Adrenal changes are also reported (3, 53, 61, 119).

A few occupational studies have suggested possible disturbances in some reproductive system functions (22, 44, 81). Several foreign low-intensity animal studies report reproductive system disturbances and cases of adverse effects on progeny (10, 40, 58, 77, 89), although contradictory evidence has also been reported (46). Of particular significance are possible genetic changes which might occur in large populations over long periods of time. Very little genetic data exists, although one U.S. study suggested a possible relationship between paternal radar exposure and mongoloidism (98).

Ocular changes, including "turbidities" or cloudiness of the crystalline lens and cataracts, which can result from microwave exposures, have been thoroughly discussed here today. The majority of existing experimental and clinical evidence on this type of ocular effect indicates that radiation damage to originally healthy eyes does not generally occur at intensities much below 100 mW/cm^2. There is, however, some limited evidence from a Soviet study which suggests that for workers having small lenticular opacities, continued work under low-intensity microwave fields (at "several mW/cm^2") can cause progressive development of the opacity formation (8).

A 1967 Polish paper (118) discussing ophthalmological aspects of safety standards for workers during operation of electromagnetic-field generators in military installations, indicates concern for workers with some eye ailments when working in microwave fields as low as 0.01 mW/cm^2. On the basis of ophthalmological examinations, workers are categorized into four groups for which maximum permissible exposure conditions are rigidly prescribed, including total exclusion of one group.

Differences in Soviet and U.S. programs are further reflected in the development of safety criteria and standards. No universal, uniform or legal standards exist in the United States and in most other Western countries. In the Soviet Union, however, comparatively stringent legal standards have been established.

In the United States, safety criteria are based upon considerations of thermal stress and damage that can occur when the average power density of these fields exceeds 10 mW/cm². This level, which presumes a margin of safety, is the recommended and most generally agreed upon criteria for indefinite exposure to microwaves in the United States and Western Europe (96). Insufficient attention has been paid to the lower frequency bands (ELF, LF, MF, HF, VHF) and to possible differences in their hazard potential. Also, no differentiation is made between pulsed and continuous wave radiation.

There is general agreement among Soviet and Eastern European investigators that systematic chronic exposure to low-intensity radiations (around 10 mW/cm² and lower) can have an adverse effect on health. Their standards are more restrictive than those of the United States by several orders of magnitude (e.g., 10 μW/cm² for continuous daily microwave exposure) (67, 96). Furthermore, separate standards exist for various frequency ranges below the microwave region (e.g., 60 kHz–30 MHz, and 30–300 MHz) (2). In Czechoslovakia maximum permissible exposures distinguish between pulsed and continuous-wave radiations and are more restrictive for the pulsed case (0.025 mW/cm² vs 0.01 mW/cm²) (67).

Regulations have been developed in Eastern European countries for screening people for work entailing r. f. exposures (1, 2, 28, 39, 82, 118). Schedules for regular periodic examinations of occupationally exposed personnel have been legally established, with special attention to ocular, neural, and cardiovascular disorders. In addition, there are regulations governing safety procedures such as shielding, and personal protection, and for appropriate work/rest cycles, vacation and sick leave policies, and workers' compensation.

In summary, considerable investment of time, money and talent have been made in foreign programs to study the effects of low-intensity occupational radio-frequency exposures in man. These studies have resulted in the accumulation of a large body of research data, which in aggregate cannot be ignored even though in many details it must be substantiated. Furthermore, these clinical studies have had a substantial influence on the overall research direction in Soviet and Eastern European countries as reflected in the large number of extended clinical studies and controlled laboratory investigations with animals at low-intensity levels. Concurrently, additional research into therapeutic applications and the development of more precise instruments for dosimetry were stimulated.

This body of data deserves serious evaluation by U.S. researchers to further clarify the implications of this research. Analogous broad clinical and epidemiological studies should be undertaken, as well as related, carefully controlled animal experiments at low radiation intensities. These foreign studies can provide valuable background and guidelines for planning future research—research which is clearly necessary and warranted on the basis of current evidence.

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CLINICAL AND HYGIENIC ASPECTS OF EXPOSURE TO ELECTROMAGNETIC FIELDS

(A Review of the Soviet and Eastern European Literature)[1]

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INTRODUCTION

It has long been apparent that electromagnetic fields impose a health hazard, especially at field intensities greater than approximately 15 mW/cm^2, which cause thermal (heating) responses in the organism. Only quite recently it is suspected, from the Soviet and East European literature, that these fields might also elicit certain functional or so-called "specific" responses, especially in the nervous system, at field intensities less than 10–15 mW/cm^2, which do not cause heating.

Prior to 1964, no comprehensive effort had been attempted in this country to review the world (especially the Soviet and East European) literature on the general biological effects of microwaves. Soviet literature was in most cases scattered, quite difficult to locate, and consequently had never come to the attention of the U.S. scientific community. When in 1964, one of the first reviews on this subject was attempted by the writer, then affiliated with the Library of Congress, it was speculated by some authorities on the subject that an extremely low yield of literature would result from the attempt. It was therefore quite surprising that a search of the Soviet and Eastern European literature on the biological effects of microwaves revealed a large and virtually unexploited body of information which had never come to the attention of the U.S. scientific community. The first review (1) contained 132 references to Soviet and East European work on this subject. Subsequent reviews by the author (2–4) and a number of others (5–9) revealed that some of the most active research in the world was being conducted in the Soviet Union and some of the Eastern European countries.

It is the purpose of this paper to review Soviet and Eastern European studies of the effects of radiofrequency fields on the human organism. An attempt will be made to summarize the more noteworthy findings of some of the literally hundreds of published works devoted to this subject and to underscore the need for a more critical and systematic treatment of this subject. This review will concentrate nearly exclusively on human clinical studies and occupational hygiene surveys and will not consider the more theoretical or experimental aspects of the biological effects of microwaves.

BACKGROUND

As early as 1933, certain Soviet scientists had already recognized that electromagnetic fields affected the human nervous system. In 1937, Turlygin (10) published one of the first comprehensive Soviet accounts of the effects of centimeter waves on the human central nervous system. He found that CNS excitability was increased by 100% of the control level when a crude spark oscillator in the vicinity of the head of a subject was switched on. In a lengthy review article, Livshits (11) cited no fewer than 28 Soviet publications on the general subject of clinical and biological microwave effects which had been published by the end of the 1930's.

During the 1940's and early 1950's, there was an understandable lull in research on this subject due to World War II. By the middle and late 1950's, there appeared a veritable deluge of Soviet literature dealing, in the main, with the clinical and hygienic aspects of microwave exposure which has continued unabated to this day. By the early 1960's, the Eastern European countries of Czechoslovakia and Poland had also become extremely active in the area of microwave exposure effects. In a cursory

[1] The views expressed by the author do not necessarily represent those of the U.S. Navy.

search of the Soviet and Eastern European literature on this subject alone, a total of about 100 publications authored by 75 researchers was found and this figure is probably a conservative reflection of the available works which are estimated to be several hundred.

In an attempt to summarize the prolific Soviet and Eastern European work on clinical and hygienic aspects of exposure to microwaves, it became apparent that a number of human systems and functions had been documented to be affected by this factor (Table 1). By far the most frequently and repeatedly reported human responses to microwaves involve the central nervous system. These responses have been noted for a wide range of frequencies (~30–300,000 MHz) at both thermogenic (>10 mW/cm²) and nonthermogenic (microwatts to milliwatts/cm²) intensities.

An often disappointing facet of the Soviet and East European literature on the subject of clinical manifestations of microwave exposure is the lack of pertinent data on the circumstances of irradiation; frequency, effective area of irradiation, orientation of the body with respect to the source, waveform (continuous or pulsed, modulation factors) exposure schedule and duration, natural shielding factors, and a whole plethora of important environmental factors (heat, humidity, light, etc.) In addition, the physiological and psychological status of human subjects such as health, previous or concomitant medication, and mental status is also more often than not omitted. These variables, both individually and combined, affect the human response to microwave radiation. Despite these omissions, however, the reviewer cannot help but be impressed both by the consistency of the findings and the large size of Soviet and East European clinical and hygienic surveys which have involved literally thousands of people over the past 20 or more years.

CLINICAL MANIFESTATIONS OF EXPOSURE TO RADIOFREQUENCY FIELDS

General Clinical Syndromes

Many Soviet clinical workers have attempted to categorize the chronological stages of human responses to microwaves. Panov et al. (12) proposed three categories or stages of responses to microwaves (Table 2). These were listed as the asthenic syndrome, characterized by fatigue, depression, and a number of other changes. This first stage is not marked by severe episodes such as fainting or dramatic changes in pulse or blood pressure and the subject responds to outpatient treatment. The second category is called the "syndrome of autonomic and vascular dystonia". The essential feature of this stage is pulse lability (brady- and tachycardia), blood pressure lability (hypo- or hypertension), EKG changes, and general neurocirculatory asthenia. Severe episodes such as fainting spells may occur and the subject requires hospitalization of unspecified nature or duration. The third stage is referred to as the diencephalic syndrome in which visceral dysfunctions and crises are observed. Typical episodes during this stage are listed as "apathic ambulic" disorders, hypersomnia, hypokinesis, hypothalamo-pituitary-suprarenal weakness, and inhibition of sexual and digestive reflexes. Panov claims that these changes are not always reversible and that subjects require hospitalization. It should be noted that Panov did not specify the nature or duration of outpatient or hospital treatment, nor did he relate these symptoms to specific irradiation parameters.

TABLE 1

Effects of electromagnetic radiation on the human organism

I.	Central Nervous System
II.	Autonomic Nervous System
III.	Neurohumoral Systems
IV.	Endocrine Glands and Functions
V.	Eye and Ocular Functions
VI.	Blood and Hematopoietic Systems
VII.	Miscellaneous Organs

General Subjective Complaints (Indirect Effects on the CNS)

A large number of East European and especially Soviet clinical and hygienic workers (13–22) have consistently and repeatedly documented an astonishing number of subjective complaints which are usually referred to as evidence of the direct or indirect effect of microwaves on the central nervous system (Table 3). These responses have been reported for a wide range of wavelengths (30–300,000 MHz) and field intensities (microwatts to several milliwatts/cm²). Unfortunately, it is often difficult to attach any significance to Soviet clinical findings in the absence of pertinent data on exposures and on patient backgrounds. Typical, for instance, was a survey conducted by Sadchikova (21) in which three groups of occupational personnel (technicians, assemblers, and maintenance workers around centi-

TABLE 2

Soviet classification of general clinical syndromes of exposure to electromagnetic radiation EMF's

A. The Asthenic Syndrome (reversible; outpatient treatment)
   1. fatigability and emotional changes
   2. acrocyanosis
   3. increased perspiration of extremities
   4. increased pilomotor reflex
   5. dermographism
   6. pulse lability
   7. blood pressure lability
B. Autonomic Cystonia (reversible; hospitalization)
   1. hyper- or hypotension
   2. bradycardia and tachycardia
   3. changes in EKG signs
   4. fainting spells
C. Diencephalic Syndrome (usually reversible; hospitalization)
   1. insomnia
   2. adynamia
   3. hypothalamo-pituitary-suprarenal inhibition
   4. inhibition of sexual function and digestive reflexes

meter wave generators) were exposed to: (1) periodic intense radiation (3–4 mW/cm²); (2) moderate radiation (tenths of mW/cm²); and (3) weak radiation (hundredths-tenths of mW/cm²). As can be seen in Table 4, the group exposed to the weakest radiation was shown to display the highest incidence of complaints. This finding and lack of pertinent exposure data such as duration and affected body area make these data difficult to accept on face value. On the other hand, Edelwejn (14) has conducted interesting and comprehensive neurological examinations and interviews of Polish personnel exposed for up to six hours/day to microwave field intensities of 10 microwatts to several milliwatts/cm². He found that many of the subjective complaints listed in Table 3 (headaches, dizzy spells, fatigue, perspiration, etc.) depended upon the length of employment and degree of exposure. Only subjects exposed to high (mW/cm²) intensities exhibited EEG changes. Edelwejn was of the opinion that there is a dramatic response to microwave exposure occurring during the first three years which are accompanied by neurotic symptoms. This three year period is followed by a phase of gradual adaptation. The reappearance of neurologic symptoms occurs after a long period (many years) of exposure to microwaves, even after adaptation has occurred.

Osipov (1965) (20) in a review of neurologic responses to microwave exposure concluded that most subjective symptoms were reversible and that pathological damage to neural structures was insignificant. Only rarely were microwaves found to cause hallucinations, syncope, adynamia and other manifestations of the so-called "diencephalic" syndrome.

Soviet workers have also documented subjective complaints identical to those in Table 3 as a result of exposure to electric and magnetic fields. Vyalov et al. (23) reported characteristic microwave symptoms such as headache, fatigue etc., in workers exposed to 150–1500 oersted magnetic fields. Asanova (24) reported analagous findings for workers exposed to 115–125 microampere fields around hydroelectric stations.

Functional Changes in the CNS

Many Soviet and Eastern European workers have attempted to identify specific CNS functional responses to microwave exposure. Most Soviet workers are of the opinion that the CNS is the most sensitive of all systems to the effects of microwaves, both at thermogenic and nonthermogenic field intensities. Based primarily upon experimental research, Presman (9) is of the opinion that the hypothalamus is the most sensitive CNS structure to microwave effects which would explain, in his view, the high incidence of blood and humoral changes noted in human subjects exposed to this factor.

Changes in human CNS function have been evaluated on the basis of EEG surveys, reflex tests, and general neurological examinations (Table 5). These changes are reported for a wide range of frequencies and field intensities (thermal and nonthermal). However, functional CNS responses appear to be de-

TABLE 3

General subjective complaints resulting from exposure to electromagnetic radiation

1. Pain in head and eyes
2. Lacrimation
3. Weakness, weariness and dizziness
4. Depression, antisocial tendencies, general irritability
5. Hypochondria, sense of fear, and general tension
6. Impairment of memory and general mental function
7. Adynamia and inability to make decisions
8. Inhibition of sex life (male)
9. Scalp sensations and loss of hair
10. Chest pain and heart palpitation
11. Dyspepsia, epigastric pain, and loss of appetite
12. Trembling of eyelids, tongue, and fingers
13. Asthma
14. Brittle fingernails
15. Sensitivity of mechanical stimulation and dermographism

TABLE 4

Changes in the nervous system as a result of exposure to microwaves

		Changes observed (in % of subjects studied)							
Group	No. examined	Headache	Increased fatigue	Increased irritability	Sleepiness	Delayed der-morgraphism	Slowed orthostatic reflex	Wrist hyperdrosis	Thyroid hypertrophy
1	184	12	20	8	2	16	19	6	15
2	129	39	31	12	14	7	21	37	—
3	78	36	31	15	19	14	11	26	52
Control	100	8	10	8	2	—	—	4	14

pendent upon wavelength; direct effects on the brain were reported by Gordon (1964) (25) and Presman (9) to intensify with increase in wavelength. However, when reactions are due to a combination of peripheral and direct stimulation, it is impossible to correlate response with wavelength.

A number of workers have reported changes in EEG patterns as a result of exposure to microwaves. Klimkova-Deutschova (26), a Czechoslovakian researcher, reported that both clinical and EEG findings suggested a predominance of an inhibition process. EEG's showed a predominance of sleep rhythms. In this connection, the interesting (if rather curious) work of Ivanov-Muromskiy (27), a Soviet expert on electrosleep and electroanesthesia deserves comment. His research on human subjects suggested that pulsed (10–1000 Hz) UHF fields of nonthermal intensity directed from bitemporal electrodes a few inches from the subject's head could induce inhibition similar to that produced by pulsed electrical currents (electrosleep). Unfortunately, this research was not described in detail by Ivanov-Muromskiy.

TABLE 5

Functional CNS changes resulting from exposure to electromagnetic radiation

1. Changes in EEG patterns
   a. "asthenic" signs
   b. predominance of inhibition process
   c. increased incidence of slow, high amplitude waves
   d. decreased incidence of alpha rhythms and waves
   e. predominance of "sleep" rhythms
2. Perceptual changes
   a. hallucinations (visual)
   b. decrease in ocular blind spot area
   c. shortening of optic chronaxie and reduction of rheobase
   d. auditory sensitivity changes
   e. decreased olfactory sensitivity
   f. increased olfactory activity
   g. parapsychologic phenomena
3. Alternating arousal and drowsiness
4. Stimulation of motor functions
5. Depression of mental functions
6. Involuntary motor reactions

Drogichina (13) reported that CNS damage is characterized by the "asthenic syndrome" which can be detected from EEG and neurological findings. Presman (9), in reviewing Soviet, Czechoslovakian, and Polish work, reports that the EEG's of subjects exposed to weak (nonthermal) microwave field intensities show an increased incidence of slow, high amplitude waves. In Poland, Edelwejn and Baranski (14) reported a decreased incidence of alpha rhythms and a decreased percentage of alpha waves in subjects exposed to "high" (mW/cm^2) intensities of microwave fields. All subjects examined in this study over-reacted to the administration of cardiozol, a respiratory and cardiac stimulant. In general, because of the rather primitive state-of-the-art of EEG analysis, these findings should be viewed with extreme caution.

Perceptual changes as a result of exposure to microwaves have also been frequently reported. Livshits (28) reported that "high intensity" microwaves had been found by Soviet workers to cause hallucinations. He also reported that high frequency, high intensity fields had been demonstrated to cause involuntary motor reactions in one healthy individual. Matuzov (29) noted visual perception changes after a 10 minute exposure to 10 cm microwaves of nonthermal (1.1 mW/cm^2) intensity. He found a considerable decrease in blind spot area,

TABLE 6

Autonomic and cardiovascular effects of electromagnetic radiation.

1. Changes in cardiac function (EKG)
   a. decreased spike amplitude
   b. lengthened QRS interval
   c. slowed auricular and ventricular conductivity
2. Bradycardia and tachycardia
3. Hyper- and hypotension
4. Increased precapillary resistance
5. Increased vascular elasticity

shortening of optic chronaxie, and reduction of rheobase in two subjects. These effects were judged to be nonthermal (specific) and were found to be reversible. Sheyvekhman (30) noted changes in auditory sensitivity (5–10 dB) in response to 6 meter waves pulse modulated at 300, 1000, or 4000 Hz applied for five minutes to the heads of human subjects. He did not clarify whether sensitivity was increased or decreased. Lobanova and Gordon (31) noted a decrease in olfactory sensitivity after exposure to microwaves and suggested that this response might be a good index for identifying harmful microwave effects. These authors also found an increase in olfactory excitability (decreased threshold) after a single dose of caffeine. This was suggested as evidence of functional olfactory changes caused by microwaves.

In the realm of parapsychology, it is interesting to note that leading Soviet researchers who strongly believe in the nonthermal CNS effects of microwaves are involved in the electromagnetic (centimeter wave) theory of extrasensory perception (3). This work, initiated in 1966, is being conducted for a special Bioinformation Section of the Scientific and Technical Society of Radiotechnology in Moscow. The results of Soviet ESP research have thus far been interesting but statistically inconclusive.

Both the stimulatory and inhibitory effects of microwaves on CNS function have been frequently documented by Soviet workers. Subbota (32) reported alternating arousal and drowsiness in response to microwaves in working with dogs. As mentioned earlier, the Soviet electrosleep expert, Ivanov-Muromskiy (27) concluded from his studies of human subjects that pulsed UHF fields could be used as a form of contactless electrosleep which he calls "radiosleep". Depression of mental function, inability to concentrate, and general sluggishness is frequently documented by Soviet and Eastern European researchers as a subjective response to microwave exposure.

Autonomic and Cardiovascular Responses

Reports of human autonomic and cardiovascular responses to microwaves are nearly as numerous as those documenting CNS responses to this factor (Table 6). Responses are noted for a wide range of frequencies at thermal and nonthermal field intensities and during acute and chronic exposure. Decreased EKG spike amplitudes have been noted by Drogichina (33) in subjects working around radiofrequency fields. Sadchikova (34) reported on various cardiovascular shifts in workers exposed to different field intensities (Table 7). Figar (15) and Smurova (35) have noted decreased coronary conductivity, sinusoidal arrythmia, brady- and tachycardia, and oscillating hypo- and hypertension. Monayenkova et al. (36) studied minute blood volume, peripheral resistance, average arterial pressure, and smooth muscle tonus using a mechanocardiograph. She found that a tendency toward hypertension, increased elasticity of myogenous vessels, increased precapillary resistance, sinus bradycardia, and changes in intracardiac conductivity were more often noted in exposed than in unexposed subjects. All of these changes were found to be reversible with one or two questionable exceptions.

There is some evidence that certain enzymes implicated in CNS function might be affected by exposure to microwaves (Table 8). Revuts'kyy et al. (37) found a change in the specific cholinesterase activity of erythrocytes in human whole blood with 13.56 and 23.75 MHz microwaves. The 13.56 MHz radiation was found to decrease blood histamine content while not altering cholinesterase activity. The 23.75 MHz radiation did not change blood histamine content but increased cholinesterase activity. Bartonicek et al. (38) surveyed the blood biochemistry of workers exposed to centimeter waves. Of a total of 27 blood sugar curves, 7 were flat, 7 were prediabetic, and four indicated slight glycosuria. The distribution of pyruvic and lactic acid and creatinine are shown in Table 9. Lactic acid was found to be decreased 2.5 times more than it was found to be increased. Roughly 75% of the subjects exposed to microwaves and examined by Bartonicek were reported to have prediabetic blood sugar curves. These metabolic shifts were attributed to autonomic dysregulation, possibly indicative to diencephalic lesions resulting from early exposure to centimeter

TABLE 7

Cardiovascular changes in subjects exposed to electromagnetic radiation (Sadchikova, 1964)

	EMF parameters	Exposure/control ratio		
Range	Field intensity	hypertonia	bradycardia	increase of QRS interval (up to 0.1 sec)
SHF	1-several mW/cm²	1.85	24.0	11.5
	1 mW/cm²	2.0	16.0	12.5
UHF	nonthermal	1.2	8.0	21.0
LF	tens to hundreds V/M	9.21	12.0	—
	hundreds to 1000 V/M	1.2	5.0	—
Percent incidence in controls		14%	3%	2%

waves. Gel'fon and Sadchikova (39) noted increased blood globulins in 50% of a group exposed to microwaves which indicated a shift in the albuminglobulin coefficient. Haski (40) noted slight changes in the levels of blood sugar, cholesterol, and lipids of healthy subjects exposed to microwaves. However, there was a pronounced decrease in all three categories when diabetics were exposed.

Hematopoietic and Biochemical Responses

Numerous human hematopoietic changes have been reported to result from exposure to microwave fields (Table 10). The severity of these changes range from minimal to significant. Sokolov (41) noted reticulocytosis in radar workers. Baranski (42) observed that a small drop in erythrocytes occurs in all people exposed to microwaves and that the phenomenon is related to the duration and severity of exposure. About 50% of the subjects examined by Baranski showed a moderate decrease in platelet count. Lysina (43) noted basophilic granularity of erythrocytes and was of the opinion that this index should be taken as an initial sign of microwave effects on the human organism. Presman et al. (44) found that the osmotic resistance of erythrocytes was negatively affected by microwaves. Smurova (22) and others found that the shape and volume of erythrocytes changes as a result of exposure to microwave fields. Prolonged exposure was occasionally noted to result in hemolytic processes. An increase in the RNA level of lymphocytes was also noted by Smurova in workers chronically exposed to microwaves; this finding corresponded to a concomitant increase in monocytes (young cells) which contain the greatest quantity RNA. Baranski (42) detected various leukocyte shifts in workers exposed for one year to microwaves. Normalization of this index was found to occur after prolonged exposure to this factor. He also found a tendency towards lymphocytosis with accompanying eosinophilia in subjects exposed for more than five years to low and moderate microwave intensities.

TABLE 8

Neurohumoral responses to radiofrequency electromagnetic radiation

1. Altered cholinesterase activity in human whole blood (erythrocytes)
2. Decrease in blood histamine content
3. Increase in blood proteins
4. Altered carbohydrate metabolism
5. Changes in blood sugar, cholesterol, and lipids (pronounced in diabetics)
6. Decreased hemoglobin

Soviet workers have also found biochemical changes to occur in other sites (8). A drop in RNA content was noted in the spleen, liver, and brain in animals chronically exposed to microwaves while DNA content was found to remain constant.

Ocular Responses

Changes in human ocular function and eye pathology are widely documented and occur primarily

TABLE 9

Distribution of pyruvic and lactic acid and creatinine excretions in workers exposed to microwaves

	Pyruvic acid		Lactic acid		Creatinine	
	number	%	number	%	number	%
No. of measurements	40	100.0	35	100.0	34	100.0
Normal	28	70.0	14	40.0	14	41.2
Increased	4	10.0	6	17.2	6	17.6
Lowered	8	20.0	15	42.8	14	41.2
Averages	0.77 mg%		14 mg%		1.33 mg%	
Controls	0.65 mg%		17 mg%		1.30 mg%	
Established standard	0.5—1.0		10—20		1.2—1.9	

after acute or chronic exposure to thermogenic microwave intensities (Table 11). As mentioned earlier, one Soviet worker (28) has reported that exposure to intense microwave fields was noted to cause hallucinations. Matuzov (29) found the area of the blind spot to decrease after exposure to nonthermogenic (10 cm; 1.1 mW/cm²) microwave field intensities. Other Soviet workers, as reported by Marha (8), have found that microwave radiation (a few mW/cm²) can cause a decrease in sensitivity to color (blue) and difficulty in detecting white objects. Changes in intraocular pressure have also been noted by Soviet workers as have altered sensitivity to light stimuli during exposure to pulsed and nonpulsed fields. General ocular pain, eye strain and fatigue, eyelid tremor, and lacrimation are also common symptoms noted by Soviet workers.

Pathological changes in the eye (cataracts) occur primarily as a result of exposure to thermogenic (greater than 10 mW/cm²) microwave intensities. Sadchikova (45) and other Soviet workers (6) have noted unilateral and bilateral cataracts to occur in subjects exposed to several mW/cm² field intensities. Presman (44) noted a drop in vitamin C content in the lens and anterior chamber fluid at nonthermogenic intensities. In the event of acute cataract development a decrease in ATP and pyrophosphatase activity of the lens was noted. In addition, it is suspected that damage to tissue respiration and oxidation mechanisms as a result of exposure to microwaves can lead to cataract formation.

There is some evidence that ocular responses to microwaves are frequency dependent. Pol (46) noted that 10 GHz fields caused anterior lens opacity while 2.45 GHz cause posterior opacity.

Belova (47) noted that in 370 microwave generator workers exposed to mW/cm², lacrimation, ocular fatigue, and frequent conjunctival irritation would occur at the end of each working day. Zydecki (48) suggested that all candidates for occupation around microwave sources receive comprehensive ophthalmological examinations. This suggests that certain ophthalomological profiles might be more vulnerable to microwave radiation than others.

TABLE 10

Hematopoietic and biochemical responses to electromagnetic radiation

1. Blood
   a. reticulocytosis
   b. basophilic granularity of erythrocytes
   c. decrease in erythrocytes, platelets and hemoglobin
   d. altered osmotic resistance of erythrocytes
   e. neutrophilic leukocytosis
   f. lymphocytosis, monocytosis, and eosinophilia
   g. increased RNA in lymphocytes
2. Organs
   a. Decreased RNA content in brain, liver, and spleen

Endocrine Responses

Damage to sex glands and functions have frequently been documented to occur after chronic exposure to primarily thermal microwave fields (Table 12). Marha (8) in reviewing Soviet and East European findings noted decreased spermatogenesis, altered sex ratio of births, changes in menstruation, retarded fetal development, congential effects in newborn babies, decreased lactation in nursing mothers, and other related responses to occur as a result of exposure to thermal (i.e., greater than 10 mW/cm²) microwave intensities. Microwaves were also implicated in an increase in the percentage of miscarriages in both humans and animals. Some of these

TABLE 11

Effects of electromagnetic radiation on the eye

1. Perceptual and function changes
   a. hallucinations
   b. decrease in size of blind spot
   c. decreased sensitivity to color (blue)
   d. difficulty in detection of white objects
   e. decreased sensitivity to light stimuli in dark adapted eye
   f. change in intraocular pressure
   g. lacrimation, ocular fatigue, and ocular pain
   h. trembling of the eyelids
   i. altered tissue respiration and oxidation-reduction processes
2. Pathological changes
   a. lens coagulation (cataracts)
   b. decrease in vitamin C content of lens and vitreous humor
   c. decrease in ATP and pyrophosphinatase activity
   d. anterior and posterior lens opacity
   e. conjunctival irritation

findings reported by Marha are consistent with subjective complaints reported by Soviet researchers such as decreased sex activity, mentioned earlier. Specific genetic changes resulting from exposure to either thermal or nonthermal microwave fields have yet to be demonstrated.

Soviet sources have reported pituitary and other endocrine responses to microwave exposure. Kolesnik (49) suggested that pituitary-hypophyseal-adrenal changes were primarily due to CNS influences on the hypophysis after exposure to microwaves. Drogichina (33, 50), Sadchikova (21, 34), and Smirnova (51) have reported thyroid gland enlargement and increased iodine-131 uptake. These changes suggest an increase in thyroid stimulating hormone (6). Hasik (40) and Presman (44) noted increased activity of the adrenal cortex to occur after microwave exposure. Murashov (52) studied 20 subjects occupationally exposed to UHF fields. He noted a reduction in plasma corticosteroid content which was attributed to lowered adrenal, or possibly sex gland androgenic activity.

TABLE 12

Endocrine responses to radiofrequency radiations

1. Sex organs and ontogenesis
   a. thermal trauma (tissue damage) to male reproductive tissues
   b. decreased spermatogenesis (sterility)
   c. altered sex ratio of births (more girls)
   d. altered menstrual activity
   e. altered fetal development
   f. decreased lactation in nursing mothers
2. Endocrine glands
   a. altered pituitary and pituitary-hypophyseal function (CNS)
   b. hyperthyroidism
   c. thyroid enlargement
   d. increased iodine-131 uptake
   e. increased adrenal cortex activity
   f. decreased corticosteroids in blood
   g. decreased glucocorticoidal activity

Miscellaneous Responses

Loshak (53) reported that various human responses, such as subjective complaints as a result of chronic microwave exposure, appeared to vary slightly with climate (Table 13). In general, responses to microwave fields were more pronounced in hot, dry climates. It was found that the electrical resistance of the skin of exposed workers was lower than in unexposed workers in a hot climate. Decreased resistance was attributed both to CNS stimulation or increased sympathetic tonus due to skin receptor reactions. These findings, while not dramatic, led Loshak to speculate that special hygienic considerations for workers exposed to microwaves in a hot climate should be exercised (improved ventilation etc.).

TABLE 13

Miscellaneous effects on electromagnetic radiation

1. Climatic effects
   a. responses to electromagnetic radiation more pronounced in hot climate
   b. decreased electrical resistance of skin in hot climate due to electromagnetic radiation
2. Internal Organs
   a. dyspepsia and epigastric pain
   b. decreased appetite
   c. liver enlargement

Orlva (54) and others have reported that workers exposed to microwaves complain of decreased appetite, dyspepsia, pain in the epigastric region, and exhibit enlargement of the liver. Marha (8) in reviewing Soviet and Czechoslovakian experimental work on animals reported that exposure to microwaves was noted to cause liver hemorrhaging, hepatic cell degeneration, and decreased filtration or renal tubules. Analogous findings for humans have not been documented.

CONCLUSIONS

The large body of the Soviet and East European clinical and hygienic findings on human responses to microwave radiation reviewed in this paper suggest that a surprisingly wide variety of neurological and physiological reactions are to be expected during exposure to nonthermal (i.e., less than 10 mW/cm²) field intensities within an extremely wide range of frequencies (approximately 30–300,000 MHz). These reactions, which are generally reversible, are often documented as a result of human exposure to field intensities as low as a few microwatts/cm². They are reported to be primarily effects upon the nervous system and reflect traditionally heavy Soviet emphasis on the central nervous system. Soviet and East European findings in this area are therefore in striking contrast to those of the West which have, in the main, documented non-CNS responses to thermal (i.e., greater than 10 mW/cm²) intensities. Only in the realm of human endocrine, visual, and skin receptor responses to thermal microwave burdens is any real substantive agreement between Soviet and Western findings to be found.

The substantially lower Soviet and East European daily maximum permissible dose (MPD) value for human exposure to microwave radiation (0.01 mW/cm² vs 10 mW/cm² in the U.S.) appears to be based upon extensive findings of human subjective and other CNS-related responses to extremely low microwave field intensities and upon considerable CNS-oriented research on animals conducted in those countries. These findings also indicate that extensive dosimetric surveys around industrial and military sources of microwave radiation have been conducted in those countries (see, e.g., the report of Marha in this collection), although the extent and nature of Soviet work in this specific area has not been well documented. In the general context of differing U.S. and Soviet MPD's and MPC's, it is important to note that the Soviet union has traditionally been more conservative with regard to many industrial hazards than the U.S.

Although the majority of Soviet findings on human responses to low intensity microwave fields must be regarded with extreme caution because of the omission of exposure and other pertinent data, it is suggested that the surprising consistency of this large body of findings merits the critical attention of the U.S. scientific community. Of particular interest is the relatively recent Eastern European work in this area. Research conducted in these countries, although heavily influenced by the Soviet Union in the early stages, appears to be of high quality; reflects a good awareness of both Soviet and Western approaches to the problem of the biological effects of microwaves; and suggests a trend towards more independent approaches to this problem. The fact that East European countries such as Czechoslovakia and Poland have adopted essentially the same maximum daily permissible dose for human exposure to microwaves as the Soviet Union is of interest and should be investigated in more detail. The Czechoslovakian MPD for microwaves, while admittedly (by Marha) influenced by the Soviet MPD, was arrived at only after considerable hygienic and dosimetric survey work had been conducted in that country. Nonetheless, it is suggested that until additional research on this difficult problem has been conducted in this country, and a more critical analysis of the available Soviet and East European findings has been made, a judgment of the U.S. 10 mW/cm² MPD is presently rendered difficult, if not impossible.

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REVIEW OF SOVIET/EASTERN EUROPEAN RESEARCH ON HEALTH ASPECTS OF MICROWAVE RADIATION*

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THIS paper will discuss the health aspects of microwave radiation in the Soviet Union and other Eastern European countries and, in some cases, will compare their approaches and views to those in the United States and Western countries. Most of the discussion will deal with research, reported human effects, and allowable safe levels of exposure in the Soviet Union because I am more familiar with the situation in the Soviet Union than in other Eastern European countries. I shall also report on the increased interchange and interaction between Soviet and Eastern European scientists and American scientists over the past seven years. This discussion will include a review of the U.S.-U.S.S.R. cooperative program on the biological effects of microwave radiation.

It would be convenient to talk about the Soviet research as if it were composed of a single approach. Generalities can be found in some features of their microwave research program, but their research methodology is as varied as those in the United States. The particular approach to a problem depends on the investigator, the institute performing the research, or both. I shall present some general statements to describe Soviet and Eastern European thinking concerning the health aspects of microwave radiation. It must be realized that these are my impressions and understandings after six visits to the Soviet Union, and that such a presentation oversimplifies a complex subject.

WESTERN AND EASTERN SCIENTIFIC EXCHANGE

For many years literature from the Soviet Union and other Eastern

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European countries have reported biological effects of microwave radiation on humans and animals at low levels of exposure (less than 10 mW/cm.^{2}). Although effects on almost all biological systems were reported, most changes dealt with alterations in the nervous system and behavior. Unfortunately, the Soviet literature in general does not provide details of experimental design and research methodology. The normal research paper usually includes the frequency of exposure (sometimes not the exact frequency, but only the designation "microwave" or a frequency band in the microwave region), the incident-power density of the radiation, the duration of exposure, and animal species. Very little, if any, information is given on how the animals are exposed, field characteristics, energy absorption, how control animals are maintained, and other important experimental design matters required for meaningful research. In most cases the bulk of the paper presents many biological changes with little description of the techniques used to measure the observed alterations. Where effects on humans are reported, exposure frequency is usually designated in such broad terms as microwaves, sometimes the range of levels measured within the general area, and sometimes the length of time the person has worked in the area are given. Little or no discussion of how the exposed and control groups are constituted and the possible presence of other environmental factors, both chemical and physical, is provided. Most reported results are subjective, and techniques used to obtain the results are often not given.

In spite of these difficulties with Soviet and Eastern European research, this large volume of data has been an important driving force in the United States in producing concern over the biological effects of microwave radiation and in generating research to evaluate the significance of microwave exposure. Attempts to duplicate some of the Soviet and Eastern European work by Western investigators have not obtained, in most cases, the same biological changes, but because of the lack of information in the Soviet and Eastern European literature, it is technically impossible to duplicate their research in all aspects. Attempts were usually concluded by a statement which read something similar to this: attempts to duplicate the results obtained by the Soviet or Eastern European investigators were unsuccessful, but, because of lack of information in their reports, we were unable to duplicate all aspects of their experiments.

An almost total lack of scientific interchange and cooperation with Soviet and Eastern European investigators before 1972 made the dilemma