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REVIEWS AND COMMENTARY

NERVOUS AND BEHAVIORAL EFFECTS OF MICROWAVE RADIATION IN HUMANS

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Following the invention during World War II of a suitable generator of microwaves for radar (*ra*dio *d*etecting *a*nd *r*anging), there has been extensive development of microwave equipment. Microwave-generating devices have been used in an increasing variety of military, industrial and civilian applications, for systems of communication, surveillance, navigation, detection and weapons control; and for heating devices such as microwave diathermy in medical and dental treatment and microwave ovens for commercial and household cooking. Along with widespread applications of microwave energy, there have been steady and large increases in power output. With respect to radar, it was noted in 1957 (1) that peak power outputs were expected to increase from 10 megawatts to 100 megawatts, and average power levels to reach possibly 1 megawatt; present average power output capacity is likely to increase significantly in the future.

As uses multiply and power output becomes greater, man is increasingly exposed to microwave energy at work and elsewhere in his daily life. The health implications or hazards of exposure to this type of non-ionizing radiation[2] need to be known so that protective standards and guides, established or proposed, will have a firm and clearly understood biologic basis.

Safety guidelines and standards developed during the 1950's were based on experimental and clinical observations and interpretations. In the USA and western European countries, the guidelines for protective practices were provided by the capacity of microwaves to produce a measurable temperature rise in irradiated tissues and by the susceptibility of certain exposed or bloodless tissues (skin, testes, lens of eye) to thermal injury. Cataractogenic effects were observed at about 100 milliwatts per square centimeter (2), a safety factor was introduced, and the result was a recom-

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[2] A segment of the radiofrequency portion of the electromagnetic spectrum has come to be known as the microwave range. It includes wavelengths from approximately 100 centimeters (cm) to less than 1 cm, and frequencies from about 30 megahertz (MHz) to 300,000 MHz. In this range are the lettered radar bands (P, L, S, C, X, K, Q, V) and the EHF, SHF, UHF, and VHF frequency band designations. The lower range of the radiofrequency portion of the electromagnetic spectrum, now generally referred to as the radiofrequency (RF) range, includes wavelengths of approximately 100 cm to 100,000 cm and frequencies of 30 MHz to 0.03 MHz.

mended maximum permissible power density of 10 milliwatts per square centimeter (10 mW/cm^2) for occupational exposure.

In the USSR and other eastern European countries, thermal effects were not used as criteria for safety standards. Instead, so-called nonthermal effects, effects reported after exposure to low levels insufficient to cause a measurable rise in temperature, were the criteria in setting maximum permissible limits. These physiologic reactions, symptom complexes and functional disorders, notably of nervous, cardiovascular and endocrine system origin, were reflected in a wide variety of sensory, behavioral, mood and performance effects (3). These effects are regarded as physiologic and functional changes which may become pathologic processes. An important objective of the standards, therefore, was to protect against possible precursors of various organic disorders (4). The official standard in the USSR was set at 10 microwatts per centimeter squared (0.01 mW/cm^2) for full-time work, a standard that is in most situations about 1000 times lower than the usual recommended level in the United States (5, 6).

Despite the several decades of extended use of microwave energy in both military and civilian applications, a very considerable amount of research and evaluation by investigators of diverse disciplines in many countries, and the setting of various guides and standards, there is very little definitive information about the health effects of human exposure to microwaves (7–9). The only epidemiologic studies (10, 11) have been small and lacking in statistical power to detect small effects with high probability and oriented toward particular end results, especially cataracts. Although it is generally agreed that radiation is harmful in sufficiently large doses whether the frequency is that of sound, ultrasound, radar, light or X radiation, the only *uncontested reported* harmful effects of microwave exposure in man are heat-related injury to the skin and the occurrence of defects in the lens of the eye. Even the cataractogenic effect in man is not yet fully documented in dose-response terms (12).[3]

The dispute that centers on claims that there are, in addition to thermal effects, nonthermal or microthermal effects—biologic responses to microwave power density too low to produce a measurable temperature rise in living tissues (less than approximately 10 mW/cm^2)—is sharpest and most speculative with respect to nervous system responses. A voluminous literature illustrates apparently opposite stands taken by theorists and experimentalists from the USSR and eastern Europe who report neural and behavioral changes induced by low-power microwaves, and scientists from the USA and western Europe who do not customarily report such effects. A similar dichotomy is apparent in reports of neurologic changes and symptom patterns in humans exposed to microwaves (13, 14).

The little experimental work that has been done on man has pointed toward possible alterations of the sensitivity of various sense organs, particularly auditory (15, 16) and olfactory (17) threshold changes. There have been numerous case reports, rumors and speculations about the role of microwave radiation in a variety of disorders of the brain and nervous system, such as a causative role in severe neurotic syndrome (18), astrocytoma of the brain (19), and a protective role in multiple sclerosis (20). In the main, however, the nervous and behavioral effects attributed to microwave irradiation at issue are those found in clinical studies of groups occupationally exposed to various intensities and frequencies of microwaves for variable but generally long periods of time.

[3] An award for service-connected disability due to radar-related bilateral cataracts, the first of its kind in the United States, was granted by the Board of Veterans Appeals to a Korean War Navy veteran on November 9, 1972. The diagnosis of cataract was made 10–15 years after multiple exposures to power densities far exceeding 10 mW/cm^2, the standard that was subsequently set.

A review of studies of exposed working groups and an analysis of studies that report findings of a neurologic or behavioral character present serious difficulties. The difficulties stem from the many kinds of publications in which pertinent material appears, the variability of data presented, the lack of similar methods and units of measurement, and the frequency of incomplete, unavailable or uninterpretable translations.

Findings from nine clinical studies (21–30) of groups employed in the operation, testing, maintenance and manufacture of a wide variety of microwave-generating equipment in Czechoslovakia, Poland, the USA and the USSR are presented in table 1. Where possible, data have been converted into similar units of measure or manner of description. While this is not a complete list or a systematic sample of studies, it shows that such published studies virtually ceased in the USA after the 1950's while considerable investigation continued to be reported from the USSR and other eastern European countries. The different national patterns of work in this field probably reflect the judgment of American scientists that laboratory study rather than clinical investigation was indicated because low-dose, long-term athermal effects had not been demonstrated, while the Russian emphasis continued on electromagnetic radiation effects on the central nervous system and early physiologic indicators of disease among industrial workers. The possible nervous system effects presented in table 1 include USA findings that were not regarded by the US investigators as either neural or significant, and Russian and other results that were considered by those investigators as indicative, even characteristic, of microwave-induced nervous system changes.

The symptoms reported in the two USA

TABLE 1

Possible nervous system effects reported in clinical studies of persons occupationally exposed to microwave radiation

Country	Investigator and year of publication: References 21–30	Source of radiation	Radiation data	Exposure history	No. of exposed	No. of controls	Possible nervous system effects*		
							Symptoms & signs	Neurologic examination	EEG changes
Czechoslovakia	Klimková-Deutschová (1963)	Industrial	3000–30,000 MHz	Long-term	72	0	+	+	+
Poland	Edelwejn, Baranski (1966)	Microwave generators	.01–3 mW/cm², pulsed & CW	Up to 6 hrs. daily; up to 10+ years	149	0	+	+	+
USA	Daily (1943)	Experimental radar	Energy as high frequency radio	Constant, daily; up to 9 years	45	0	+		
	Barron, Love, Baraff (1955) Barron, Baraff (1958)	Radar for aircraft	400–9000 MHz, pulsed, 3.9–13.1+ mW/cm²	Up to 4 hrs. daily; up to 13 years	335	88	+		
USSR	Sadchikova (1960)	Radar generators	Mainly 3000 & 10,000 MHz; .01–4 mW/cm²	Up to 10+ years, periodic	525	100	+	+	
	Kapitanenko (1964)	Radar	300–3000 MHz	Chronic	66	34	+		
	Smurova et al. (1966)	Physiotherapy generators	1.6–2450 MHz, 170–1000 mW/cm²	Chronic	?	?	+		
	Ginzburg. Sadchikova (1968)	Radiowave sources	a) 300–3000 MHz up to 3 mW/cm²	2–26 years, periodic & continuous	65	0	+	+	+
			b) 3–30 MHz up to 16.6 mW/cm²		26	0	–	–	+
	Sadchikova, Glotova, Chulina (1968)	TV, radio station transmitters	170–212 MHz, .007 mW/cm², & 69–74 MHz, .24 mW/cm²	6 mos.–5 years continuous & periodic	110	0	+	–	

* +, reported; –, not found; no symbol, not tested.

studies include "typical frontal headache", and occasional intraocular pain, fatigue, nervousness, awareness of buzzing vibrations or pulsations, and a sensation of warmth—all mild complaints which did not interfere with work or sleep or require treatment.

The symptoms and signs commonly described in the Soviet and other studies include headache, increased fatigability, increased irritability, dizziness, loss of appetite, sleepiness, sweating, difficulties in concentration or memory, depression, emotional instability, dermographism, thyroid gland enlargement and tremor of extended fingers. They are regarded as typical microwave-induced functional disturbances of the central nervous system and are called the neurasthenic or asthenic syndrome (the term "neurasthenia" originated in the USA a century ago but has been almost obsolete in this country for some decades (31)). Another frequently described manifestation of microwave irradiation is a set of labile functional cardiovascular changes including bradycardia (or occasional tachycardia), arterial hypotension (or hypertension) and changes in cardiac conduction. This form of neurocirculatory asthenia or vagotonic reaction, known as the vegetative dystonia or autonomic dystonia syndrome, is attributed to neural influence mainly from the parasympathetic division of the autonomic nervous system. A third group of findings, more serious but less frequent than the others, includes hallucinations, insomnia, syncope and inhibition of visceral functions; it also is associated with microwave exposure and is called the diencephalic syndrome.

In the clinical appraisal, routine neurologic examination appears to add little to the history and general physical findings beyond descriptions of hand tremors, dermographism and rare ataxia. Electroencephalographic (EEG) changes are variously described as showing decreases in the alpha wave index, increases in theta and delta wave percentages, and poor tolerance of the Cardiazol test, and are reported to range in significance from preclinical warnings of subtle microwave changes to evidence of disorders of the diencephalon. Correlations between EEG changes and other clinical observations and subjective complaints have been made but do not appear consistent.

Characteristics of the clinical syndromes, and also the EEG shifts, have been related to the power density of the field, duration of exposure, modulation, wavelength and other characteristics of the radiation. Repeatedly, the frequency and severity of clinical signs are reported to increase with long-term exposure. The clinical syndromes, but not necessarily the EEG changes, are generally found to be reversible with temporary (or permanent) removal from work and with symptomatic and general supportive treatment on an outpatient basis, although in a small proportion of cases inpatient or domiciliary care has been advised.

In the clinical studies considered and reviewed, there is infrequent and casual use of control groups which, when used, seem to be inserted because studies are expected to have controls rather than to control for relevant study variables. Thus, there are no adequate descriptions of requirements for selection of controls. For example, study subjects consistently outnumber controls, there are important differences between exposed and controls in age distribution and occupation (when the information is provided), and nonexposed groups are given less complete and assiduous followup and examination. These shortcomings, added to the lack of objective criteria for assessing many of the observed clinical phenomena, the problems of subject variation and observer variability, and the inadequacies and uncertainties of radiation measurement and exposure data, make it impossible to determine from existing clinical studies that microwaves can or cannot induce neural or behavioral changes in man.

It seems desirable, however, to take advantage of marked occupational differences in levels of exposure. At this time, man's exposure to microwave radiation cannot be measured by a personal device such as a film badge, so that the only measurements possible (except in some experimental situations) are environmental or arise out of efforts to reconstruct the circumstances of an accidental exposure. Furthermore, the dosimetry of occupational exposure will not permit the assignment of exposure or dose to any large number of individuals because the necessary measurements are complex and costly.

If reasonably controlled occupational comparisons can be made for sufficiently long periods of time, with groups that are comparable in important demographic, social and health characteristics, health effects associated with microwave exposure could be revealed. For example, if it can be demonstrated that highly-exposed electronics workers do indeed have more ill-defined complaints and illnesses, higher rates of absenteeism due to illness, poorer performance records, greater hospital, clinic or physician attendance rates, increased liability to accidents, and the like, such leads are a valuable source for further investigations of specific microwave effects.

The leads so far provided by theoretical and experimental work, at least in this country, have not been notably productive in furthering human studies. The lack of reliable devices for measuring absorbed energy in biologic materials, and the complexities of species-dependent, frequency-dependent dosimetry, have discouraged both the application of laboratory findings to the human situation and the conduct of human studies.

It may be that little pathology has been observed because the bulk of the exposure is at low dose levels where any risk of untoward sequelae is not large enough to produce effects that can be easily detected. Perhaps the protective guides and standards have served to prevent the escalation of occupational exposure as the uses for microwave radiation multiplied and the power of equipment steadily advanced. It may also be that systematic efforts have not been made to identify and follow exposed and nonexposed persons adequately and for sufficiently long periods of time. The growing body of Russian and eastern European literature describing a wide variety of functional changes and clinical effects, leading to consideration of "radio-wave sickness" as a possible independent nosologic entity (32), cannot simply be ignored. With increasing uses and power, the stage is set for the appearance of late effects previously undetected possibly because of their infrequency, lack of distinctiveness or mild character. There may now be a better opportunity to resolve the uncertainties of present knowledge in the face of an increasing risk.

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