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Biological Effects of Microwave Radiation

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The possibility of exposure of large segments of the population to complex, multifrequency microwave radiation in the environment is now a reality. It is necessary, therefore, to determine the safe level of exposure for the general population so as to prevent any occurrence of harmful effects without unduly restricting the beneficial uses of microwaves.

The biological effects generated by exposure to microwave radiation are usually designated as thermal or nonthermal (specific) in nature. Thermal effects are those interactions which are caused by the heating of the biological specimen and can be duplicated using conventional heating techniques. Nonthermal or specific effects are due to the direct interaction of the electromagnetic field of the incoming microwave radiation and the biological specimen.

The two organs of the body which are particularly sensitive to elevation in temperature are the testicles and the eyes. These organs, therefore, are the most sensitive to exposure to microwave radiation. Research on dogs, rabbits, and rats has shown that at 10 mW/cm, (power density in milliwatts per square centimeter) pathological damage to the testes include a degeneration of the epithelium lining of the seminiferous tubules, and a sharp reduction in the number of maturing spermatocytes. The reduction in testicular function due to the heating effect at 10 mW/cm^2 appears to be temporary and reversible.

Cataracts have been produced in the eyes of experimental animals. Several investigators have used the eyes of rabbits to establish threshold for cataract formation. For CW radiation, the threshold in rabbits for long-term exposure, was measured to be approximately 100 mW/cm^2. Several cases of eye cataracts in man due to microwave exposure have been reported at power densities of the same order of magnitude. More research is needed before threshold values for cataract formation in humans can be specified with certainty.

Nonthermal or specific effects are more difficult to detect than the thermal effects. This difficulty is due to the nature of the response of the biological specimen and the lack of explanation of the mechanism causing the effect. The most often reported effects of low level microwave radiation are neurological in nature. Effects on animals include changes in EEG patterns, changes in the conditioned reflexes, alterations in sensitivity to light, sound, and olfactory stimuli, alterations in the biocurrents of the cerebral cortex, and changes in behavior. Many subjective symptoms in humans working around microwave equipment have been reported by investigators from the U.S.S.R. and Eastern European researchers.

Genetic effects have been reported by some investigators. Exposure of chick embryos to microwave radiation induced abnormal development while conventional heating to the same temperature did not cause abnormalities. In general, the abnormalities appeared to be caused by the inhibition of growth and cell differentiation. Abnormal development of the "mealworm" beetle pupae has also been detected when exposed to microwave radiation. This study also indicates that the abnormalities were not due to thermal effects but due to the inhibition of cell differentiation caused by a direct interaction with the electromagnetic field.

The use of microwave radiation in domestic and commercial ovens, industrial processing, communications, radar, and medical diathermy has greatly increased over the past ten years, and will increase even faster over the next ten years. With this increased use of microwave radiation, the possibility for larger segments of the population to be exposed to complex microwave fields is enhanced.[1,2] Therefore, it is essential that safe exposure levels be specified in order to protect individuals from harmful effects, but at the same time not to restrict unduly the beneficial uses of microwave radiation.

At present, there exist large differences in the accepted safe level of exposure between the United States and Western European Countries, and U.S.S.R. and Eastern European Countries. The United States, United Kingdom, France, and West Germany have generally accepted a power density exposure level of 10 mW/cm². The USSR and Poland specify a permissible level of 0.01 mW/cm², which is a factor of 1000 less than that accepted by the U. S. and other western countries. Czechoslovakia has proposed a level of 0.025 mW/cm² for an average working-day exposure. A summary of maximum permissible intensities is presented in Table I.

The fact that there is a factor of 1000 between the accepted U. S. standard and the Eastern European standard results from the different basis for determining biological effects. The U. S. accepted standard is based upon the cooling capability of the body (thus, a thermal effect), whereas the standard of the U.S.S.R. and Poland are based upon the interaction of the microwave fields with the brain and central nervous system as measured by neurological or behavior effects.

Many studies have been made on the biological effects of microwave radiation. The effects are usually designated as thermal or nonthermal in nature depending upon the mechanism of the interaction. Thermal effects are those effects which result from heating of the biological material and can be duplicated by conventional means. Nonthermal effects or specific effects are those effects which result from the interaction of the electromagnetic field with the biological material and cannot be produced by conventional heating techniques. It should be noted here that some disagreement exists among investigators as to whether nonthermal effects actually occur at low power levels. Much of this disagreement is due to the lack of accurate quantitative measurements of the microwave energy absorbed by biological specimens when exposed to microwave fields.

Biological Effects

The thermal effects of microwave radiation on biological material are best understood and are summarized in Table II.[3] As can be seen from the information in Table II, microwaves of frequencies greater than 10,000 MHz (short wavelengths) do not penetrate beyond the skin and produce only skin surface heating. Microwave radiation of frequencies less than 150 MHz (long wavelengths) penetrate the body with very little loss in energy. The most susceptible organs of the body to thermal effects for frequencies between 150 and 10,000 MHz are the testicles and the eyes. The testicles are extremely sensitive to elevations in temperature. Ely et al.[4] performed a study on dogs, rabbits, and rats in order to determine the threshold for testicular damage. They determined that 10 mW/cm² was the threshold for testicular damage for indefinite exposure. The pathological damage found in the testes includes a degeneration of the epithelium lining of the seminiferous tubules, and a sharp reduction in the number of maturing spermatocytes in the lumen. The reduction in testicular function due to the heating effect at 10 mW/cm² appears to be temporary and probably reversible.

The possibility of damage to the eye is a very serious aspect of microwave radiation. Cataracts have been produced in the eyes of experimental animals.[5–9] Several investigators[4,7–9] have used the eyes of rabbits (due to their similarity to the eyes of humans) to establish thresholds for cataract information. These power-time thresholds are shown in Figure 1 and are for exposure to continuous wave radiation. The data presented in Figure 1 show that the power-time thresholds are a strong function of the frequency of the radiation. The difference in the threshold levels presented for the same frequency is due to different criteria for designating initial onset of damage and different techniques for measuring the initiation of damage. Threshold levels for pulsed radiation and accumulative effects have not been adequately established.

Table I. Maximum permissible intensities.

Institution or Country	Frequency, MHz	Maximum permissible intensity in mW/cm²	Remarks
U. S. Standards Institute C95.1-1966	All	10 1 mW hr/cm²	For periods of 0.1 hours or more during any 0.1-hr period
U. S. Army and Air Force (1965)	All	10	Maximum permissible level for continuous exposure
		10–100	Limited occupancy exposure time[a] $T_p = 6000/W^2$
	All	Over 100	Denied occupancy
United Kingdom (1963)	30–30,000	10	Continuous daily exposure in case of pulsed waves, an average over the complete train of pulses
France (1965)	All	10	For 1 hr or longer Formula — $T_p = 6000/W^2$ for periods less than 1 hr
West Germany	All	10	No allowance made for time of exposure
USSR (1958)	300–30,000	0.01	Whole working day
		0.1	2–3 hr daily
		1	15–20 minutes daily
Poland (1961)	Over 300	0.01	Whole working day
		0.1	2–3 hr daily
		1	15–20 min daily
Czechoslovakia (1965)	Over 300	.025	Continuous exposure
		.01	Pulsed exposure

[a] T_p is the time of exposure in units of minutes, W is the power level in units of milliwatts/square centimeter.

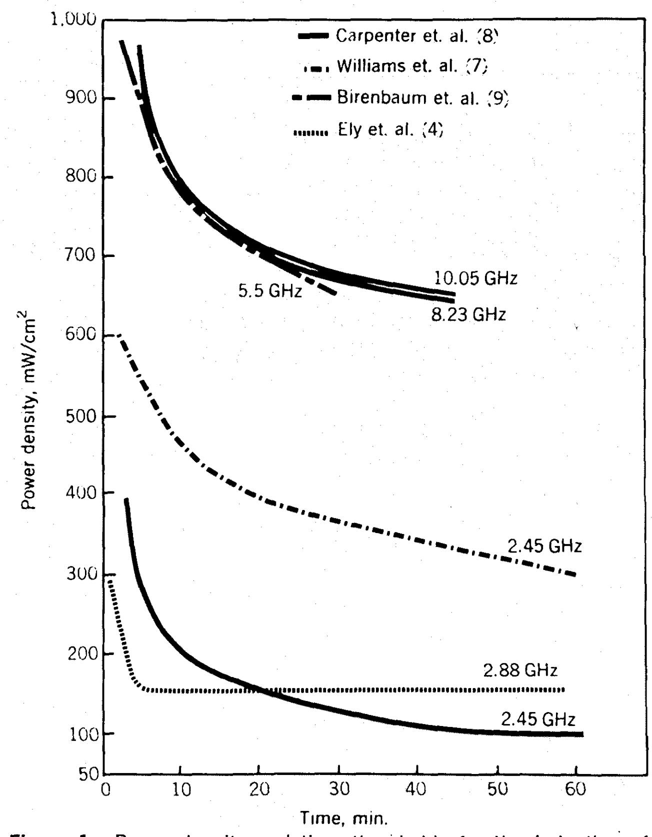

Figure 1. Power density and time thresholds for the induction of opacities in the eyes of rabbits.

Several cases of cataracts in man following accidental exposure have been reported. In 1952, Hirsch[10] reported the first case of cataract formation in a technician operating a microwave generator at a frequency range of 1500–3000 MHz. His eyes were exposed daily for approximately one year to an estimated power density of 100 mW/cm². Zaret[11] has reported three cases of cataracts in individuals who had histories of repeated microwave exposure. The estimated power levels were from 350 mW/cm² to several watts/cm². The length of time between exposure to microwaves and opacity formation ranged from two months to many months depending on the power density of the radiation. From the limited information on human eyes, the threshold power-time curves of rabbits appear to be of the correct magnitude. However, until more information is obtained, the rabbit threshold curves should only be used as guides and not absolute values.

Nonthermal or specific effects, which result from exposure to low-level microwave radiation, are more difficult to detect than those mentioned above. This difficulty is due to the nature of the response of the biological specimen and the lack of explanation of the mechanisms causing the response. The first non-thermal effects to be considered will be neurological effects or effects on the brain and central nervous system. Marha[12] has listed the subjective complaints of persons working in radio frequency fields (Table III). He lists many references from which he obtained this information. These references are from the Russian and Czechoslovakian literature and attempts to obtain copies of the articles have proved discouraging. Therefore, details such as the number of workers, the frequency, power level, type of radiation (continuous, pulsed or modulated), and duration of exposure are not known. Minecki[13] from the Institute of Occupational Medicine, Lodz, Poland, has obtained results similar to those of Marha. Clinical observations of 146 persons occupationally exposed to microwaves ranging in frequency from 750 KHz to 200 MHz are presented in Table III. The workers were divided into two groups depending upon the time of employment. The two groups were almost uniform with respect to age distribution. The frequency of the symptoms increased with time of exposure. In order to determine the exposure condition, radiation intensity measurements were made in all the working areas. The maximum values of intensity did not exceed 3 mW/cm² and the average values in different plants were not higher than 1 mW/cm². These levels are significantly lower than the accepted safe level of the U. S. of 10 mW/cm².

Letavet and Gordon[14] have reported clinical evidence of the effects of chronic low-power-density microwave radiation. The reported effects of chronic occupational exposure of the 525 microwave workers examined during the study are listed in Table IV. In addition to the above results, there was a high incidence of subjective complaints among the workers and these are also listed in Table IV. Statistical analysis of these findings are not reported in the studies.

Kholodov[15] has reported specific effects of microwaves on animals, Table IV. A large portion of his studies have been performed using rabbits as biological specimens. Both thermal and nonthermal power flux densities were used. For the low power density studies he used pulsed 2.5 GHz fields ($\lambda = 12$ cm) of 2 and 10 mW/cm² average power. The tests were conducted on 14 rabbits, which received a combined total of 300 exposures. Using EEG measurements, an increase in biopotential amplitude which was sometimes accompanied by a decrease in biopotential frequency was observed most frequently (76% of the total number of reactions). In 20% of the cases, a prolonged desynchronization reaction was observed.

Presman and Levitina[16] studied the nonthermal effects of microwaves on cardiac rhythm. The experiment was carried out on 8 male rabbits. Each animal was irradiated 12–13 times for 20 minutes at power levels of 7–12 mW/cm² and a frequency of 2500 MHz. Irradiation of the ventral side of the rabbits caused a decrease in the heart beat, and the irradiation of the dorsal side of the head and body increased the heart beat. The effect was attributed to central nervous system stimulation as a result of irradiation of the head, as contrasted to stimulation of peripheral receptors and the autonomic nervous system from ventral irradiations.

All the effects presented in Tables III and IV are results of studies made in USSR or Eastern European countries. Clinical studies of microwave workers conducted in the United States by Daily[17] and Barron and Baraff[18] in contrast to the findings of Minecki[13] and Letavet and Gordon,[14]

Table II. Thermal-biological effects of microwaves.

Frequency, Mega Hertz	Wavelength, cm	Site of major tissue effects	Major biological effects
>10,000	<3	Skin	Skin surface acts as reflector or absorber with heating effects
10,000	3	Skin	Skin heating with sensation of warmth
10,000 to 3,300	3 to 10	Top layers of skin, lens of eye	Lens of eye and testicles particularly susceptible
10,000 to 1,000	3 to 30	Lens of eye	Critical wavelength band for eye cataracts and testicular damage
1,200 to 150	25 to 200	Internal body organs	Damage to internal organs from overheating
<150	Above 200		Body is transparent to waves above 200 cm

Table III. Neurological effects.

Subjective effects on persons working in Rf fields[12]	Occurrence of some symptoms in humans exposed professionally to high frequency electromagnetic fields (750 KHz–200 MHz)[13]				
		Length of employment, 73 persons			
		1–6 years (in average 4.3)		7–16 years (in average 9.6)	
Symptoms	Symptoms	Percent of cases	Number of cases	Percent of cases	Number of cases
1. Headaches	Headache	20.5	15	32.9	24
2. Eyestrain	Disturbance of sleep	13.7	10	23.3	17
3. Fatigue	Fatigue	12.3	9	17.8	13
4. Dizziness	General weakness	7.0	5	12.3	9
5. Disturbed sleep at night	Disturbance of memory	5.5	4	8.2	6
6. Sleepiness in daytime	Lowering of sexual potency	5.5	4	8.2	6
7. Moodiness	Drop in body weight	2.7	2	12.3	9
8. Irritability	Disturbance of equilibration	5.5	4	11.0	8
9. Unsociability	Neurological symptoms	0.0	0	15.1	11
10. Hypochondriac reactions	Changes in ECG	17.8	13	28.8	21
11. Feelings of fear					
12. Nervous tension					
13. Mental depression					
14. Memory impairment					
15. Pulling sensation in the scalp and brow					
16. Loss of hair					
17. Pain in muscles and heart region					
18. Breathing difficulties					
19. Increased perspiration of extremities					
20. Difficulty with sex life					

indicated no acute, transient, or cumulative, physiological, or pathological changes which could be attributed to microwave exposures. There have been, however, reported effects of low level microwave exposure on the central nervous system by U. S. and Canadian investigators.

Frey[19] has found that the perception of sound can be induced in humans irradiated with modulated microwave radiation. Frey has also detected evoked electrical potential in the brain stem of cats as a result of irradiating with pulse-modulated UHF fields. Frey states that the effects are definitely present and that a description of the mechanism producing the effects is needed in order to evaluate the potential hazard.

Table IV. Neurological effects. Clinical manifestations of chronic occupational exposure of humans to microwave radiation.[14]

1. Bradycardia
2. Disruption of the endocrine-humoral process
3. Hypotension
4. Intensification of the activity of thyroid gland
5. Exhausting influences on the central nervous system
6. Decrease in sensitivity to smell
7. Increase in histamine content of the blood

Subjective complaints

1. Increased fatigability
2. Periodic or constant headaches
3. Extreme irritability
4. Sleepiness during work

Effects of electromagnetic fields on the central nervous system of animals[15]

1. Changes in the conditioned reflexes
2. Alterations in sensitivity to light, sound, and olfactory stimuli
3. Changes in structure of skin receptors of the digestive and blood carrying system
4. Alteration in the biocurrents of the cerebral cortex
5. Reversible, structural changes in the cerebral cortex and diencephalon
6. Appearance of various vegetative reactions

Hearn[20] has studied the effect of long continuous exposure of albino rats to low level RF fields. He looked at the effects on visual acuity and the frequency at which a flickering light appears to become steady. This flicker threshold is a sensitive well-established indicator of brain function. Hearn's results showed significant differences in the flicker thresholds of the irradiated as compared to the non-irradiated subjects. Korbel and Thompson[21] have found differences in behavior of rats exposed to low-intensity UHF radiations as compared to the unexposed. Tanner et al.[22] have exposed birds to very low power microwave fields. Marked changes in the behavior patterns were observed. The birds became hyperactive in their attempts to escape the field. The escape reaction manifested itself in either initiating flight, flanking (orienting body a certain way with the field), or collapsing. Infrared heating of the birds at very high levels did not evoke the behavior produced by the microwave fields.

Genetic effects have been produced by microwave fields. Van Ummersen[23] exposed chick embryos at the 48-hr stage of development to 2450 MHz CW radiation through the intact shell. The power density was of the order of 20 mW/cm^2 and the length of exposure was from 280 to 300 min. The temperature of the yolk was increased to 42.5°C, a rise of 3.5°C above normal incubator temperature. In general, the abnormalities appeared to be caused by the inhibition of growth and cell differentiation. Many embryos were only as large as 72-hr rather than 96-hr embryos. In many cases, further cell differentiation of the brain, eye, wing buds, and heart had been inhibited. Development of hind limbs, tail, and allantois was suppressed.

To investigate whether the 3.5°C increase in temperature over the incubation temperature was the cause of the abnormalities, 41 fertile control eggs were incubated at a 42.5°C temperature level for the same length of time; the experimental eggs had been raised to 42.5°C by the microwave radiation. No abnormalities were found in the eggs which had been incubated at the elevated temperature of 42.5°C. Van Ummersen concluded that since the microwave radiation induced abnormal development of the chick embryos, while conventional heating to the same temperature did not cause abnormalities, some factors other than a thermal one produced the biological effect.

Carpenter et al,[24] observing that microwaves appeared to inhibit cellular differentiation in the developing chick embryos, performed studies on pupae of the "mealworm" beetle (Tenebrio molitor). He exposed the pupae to microwaves of a frequency of 10,155 MHz at power densities of 80 and 20 mW/cm^2. The results of Carpenter's studies are presented in Table V.

The different grades of abnormal development are as follows:

Grade 1 anomaly—normal head and thorax, pupal abdomen with pupal case sometimes attached; wings and/or elytra (wing covers) absent, reduced, or shredded.
Grade 2 anomaly—normal adult head, thorax, and abdomen, wings and/or elytra rumpled or shredded,
Grade 3 anomaly—normal adult except for discrete holes in elytra.

At the exposure to 80 mW/cm^2 power density, the temperature rise in the pupa abdomen, as measured by a fine copper-constantan thermocouple, was 12.5°C. The temperature of 20 control pupae was increased by 12°C for 20 min by conventional heating. In these 20 controls, there were no deaths, 75% emerged normal, and 25% exhibited abnormalities. Another 20 control pupae were heated to a 3°C temperature rise (corresponds to 20 mW/cm^2 exposure) by conventional means. Of these 20, 17 or 85% developed normally as opposed to only 24% for those exposed to microwaves and raised to the same temperature. From these studies, Carpenter et al.[24] conclude that the effect cannot be explained as a thermal effect, but rather a specific effect caused by the interaction of the microwave field and the biological specimen.

Other genetic effects have been reported. Heller and Teixera-Pinto[25] reported rf-induced chromosomal aberrations in garlic root tips at a frequency of 27 MHz. Janes et al[26] reported microwave induced chromosomal effects in a study using chinese hamsters at a frequency of 2450 MHz. Mickey[27] observed two types of effects on Drosophila when exposed to pulsed UHF fields (5–40 MHz): pathological somatic changes, not hereditarily transmitted, and hereditarily transmitted changes in the germ cells. Heller et al.[28] showed that mutagenic effects similar to those of ionizing radiations could be produced in bacteria, spores of lower fungi and higher plants, and insects by exposure to pulsed electromagnetic fields. It is impossible to evaluate the effects listed in this paragraph in terms of thermal or nonthermal mechanisms due to the lack of measurements and controls on the experiments.

Only one statement on the possible genetic effects of microwave radiation on humans has been reported. Sigler et al.[29] reported that there was a higher incidence of Down's Syndrome in children whose fathers had prior occupational exposure to radar. The authors realized the questionable statistical validity of their study and only suggest the relationship between mongolism and paternal radar exposure.

Discussion

A critical review of the literature on the biological effects of microwave radiation immediately reveals the limitations and inadequacy of much of the work. In many cases this situation is not the fault of the investigators but rather is due to the many difficulties in quantitating experiments in this area of research. Accurate, quantitative experiments are difficult to achieve because the microwave field interacts with the detectors which are placed in the biological specimen. The presence of these detectors, usually thermocouple or thermistor probes, can cause hot spots in the biological material. Due to the complex nature of electromagnetic radiation, it is very difficult to evaluate the magnitudes of these extraneous effects. Extreme care must be taken in all studies in order to eliminate these artifacts. In general, the usefulness of much of the reported results has been minimized due to the unanswered questions concerning the work. Many of the investigations were performed without adequate measurements of the exposure and dosimetric parameters. Insufficient controls on the biological specimens were maintained during exposure. Few mechanisms of interaction of the specimen with the electromagnetic field were specified. Many of the described biological effects were not evaluated in terms of their hazard potential (that is to say, is the biological effect harmful to human health or to the environment in which he lives?).

The USSR, which has a safe exposure level 1000 times less than the U. S., has reported behavioral and neurological effects at very low power levels. As indicated in a previous section, many of the effects are subjective in nature (headaches, fatigue, etc.). In many cases, the reports of the work used to support these effects do not specify the exact param-

Table V. Effect of 10,000-MHz radiation on Tenebrio Molitor pupae.[24]

	Period of time in waveguide	Microwave power in waveguide	Pupal deaths	Grade 1 anomaly	Grade 2 anomaly	Grade 3 anomaly	Normal adults	Total
Untreated controls	None	None	7 (5.1)	6 (4.4)	2 (1.5)	0 (0)	122 (89)	137 (100)
Waveguide controls	20 min	None	0 (0)	0 (0)	1 (3.4)	0 (0)	14 (93)	15 (100)
	30 min	None	1 (3.4)	1 (3.4)	1 (3.4)	0 (0)	26 (89.6)	29 (100)
Irradiated pupae	20 min	80 mW	20 (25)	22 (27.5)	10 (12.5)	9 (11.9)	19 (23.7)	80 (100)
	30 min	80 mW	8 (22.9)	7 (20)	1 (2.8)	7 (20)	12 (34.3)	35 (100)
	120 min	20 mW	1 (4)	4 (16)	10 (40)	5 (20)	5 (20)	25 (100)

eters and conditions of the experiments. Therefore, in the U. S. many of our scientists doubt the validity of the very low USSR standard. It must be recognized, however, that the Russian scientists have placed much more emphasis and research effort into the study of the effects of electromagnetic radiation on the brain and central nervous system than the U. S. scientists. Since their safe level of exposure is based on these neurological and behavior effects, it is my opinion that we should not neglect the USSR results until we have sufficient proof that the effects of microwaves on the brain and central nervous system are not detrimental to the health and well-being of our people.

Conclusions

Many questions remain to be answered before safe levels of microwave exposure can be specified. Some of the studies necessary to answer these questions have been started[30] and will be reported here. The development of techniques and instrumentation for the determination of the exposure and dosimetric parameters should be emphasized so that quantitative research can result. Epidemiological and clinical investigations should be undertaken of groups of workers exposed to high and low levels of microwave radiation. In particular, behavioral and physiological effects should be investigated, especially as they may be related to functions of the central nervous system or to congenitally derived disorders. Studies on animals should be undertaken with particular emphasis on the detection of possible nonthermal and cumulative effects. Exposures to continuous, modulated, and pulsed fields should be performed. Frequency specific effects, influence of pulse repetition rate, peak power and average power density should be studied. Research is needed on the interaction of microwave radiation with tissues and cells in various organ and animal systems. Possible genetic and mutagenic effects of microwaves should also be explored. In all these studies, mechanisms of interaction of the microwave radiation and the biological system must be determined. The biological effect must also be interpreted in terms of its hazard potential to man and his environment.

References

1. Joint Report by the Department of Defense and the U. S. Department of Health, Education and Welfare, "A partial inventory of microwave towers, broadcasting transmitters, and fixed radar by states and regions," BRH/DEP 70-15 (1970).
2. J. Y. Harris, "Electronic product inventory study," BRH/DEP 70-29 (1970).
3. Environmental Health Series, U. S. Department of Health, Education and Welfare, "Regulations, Standards and Guide for Microwave, Ultraviolet Radiation and Radiation from Lasers and Television Receivers, An Annotated bibliography," 1969.
4. T. S. Ely and D. E. Goldman, "Heating Characteristics of Laboratory Animals Exposed to 10 cm Microwaves," Proceedings of Tri-Service Conference on Biological Hazards of Microwave Radiation, 1957.
5. L. E. Daily, Jr., "Effects of microwave diathermy on the eyes," *Amer. J. Physiol.* **155:** 432 (1948).
6. A. W. Richardson, T. D. Duane, and H. M. Hines, "Experimental lenticular opacities produced by microwave irradiation," *Arch. Phys. Med.* **29:** 765 (1948).
7. D. B. Williams, J. P. Monahan, W. J. Nicholson, and J. J. Aldrich, "Biologic effects studies on microwave radiation time and power thresholds for production of lens opacities by 12.3 cm microwaves," *A.M.A. Arch. Ophth.* **54:** 863 (1955).
8. R. L. Carpenter, "An Experimental Study of the Biological Effects of Microwave Radiations in Relation to the Eye," RADC-TDR-62-133, 1962.
9. L. Birenbaum, G. M. Grosof, S. W. Rosenthal, M. M. Faret, "Effects of microwaves on the eye," *IEEE Transactions on Biomedical Engineering*, **BME-16**(1): 7 (1969).
10. F. G. Hirsch and J. T. Parker, "Bilateral lenticular opacities occurring in a technician operating a microwave generator," *A.M.A. Arch. Indust. Hyg.* **6:** 512 (1952).
11. M. M. Zaret, "An experimental study of cataractogenic effects of microwave radiation," Technical Documentary Report No. RADC-TDR-64-273. Rome Air Development Center, Griffiss AFB, N. Y., 1964.
12. K. Marha, J. Musil, and H. Tuha, *Electromagnetic Fields and the Life Environment*, San Francisco Press, Inc., San Francisco, 1971.
13. L. Minecki, "Critical evaluation of maximum permissible levels of microwave radiations," *Arhiv. za Higijenu Rad. i Toksikologiju* (*Zagreb*) **15:** 47 (1964).
14. A. A. Letavet and Z. V. Gordon, "The biological action of ultra-high frequencies," *Acad. Med. Sci. U.S.S.R.* Translated by U. S. Joint Publ. Research Ser., 12471 (1962).
15. Y. A. Kholodov, "The effects of electromagnetic fields on the central nervous system," *Priroda* **4:** 104 (1962).
16. A. S. Presman and N. A. Levitina, "Nonthermal action of microwaves on cardiac rhythm," *Biul, Eksper, Biol. Med.* **53**(1): 41 (1961).
17. L. E. Daily, "Clinical study of results of exposure of laboratory personnel to radar and high frequency radio," *U. S. Navy Med. Bull.* **41:** 1052 (1943).
18. C. I. Barron and A. A. Baraff, "Medical considerations of exposure to microwaves (Radar)," *J. Amer. Med. Assoc.* **168:** 1194 (1958).
19. A. H. Frey, "Biological function as influenced by low-power modulated RF energy," *IEEE Transactions on Microwave Theory and Techniques.* **MTT-19**(2): 153 (1971).
20. G. E. Hearn, "Effects of UHF Radio Fields on Visual Acuity and Critical Flicker Fusion in the Albino Rat," Ph.D. dissertation, Baylor University, Waco, Tex. *Univ. Microfilms* **65**-10,002 (1965).
21. S. Korbel and W. D. Thompson, "Behavioral effects of stimulation by UHF radio field," *Psychol. Rep.* **17:** 595 (1965).
22. J. A. Tanner, C. Romero-Sierra, and S. J. Davie, "The effects of microwave on birds: preliminary experiments," *J. Microwave Power* 4(2): 122 (1969).
23. C. A. Van Ummersen, "An Experimental Study of Developmental Abnormalities Induced in the Chick Embryo by Exposure to Radio Frequency Waves," Ph.D. dissertation, Dept. Biol., Tufts University, Medford, Mass., 1963.
24. R. L. Carpenter and E. M. Livstone, "Evidence for nonthermal effects of microwave radiation: Abnormal development of irradiated insect pupae," *IEEE Transactions on Microwave Theory and Techniques*, **19**(2): 173 (1971).
25. J. H. Heller and Teizeira-Pinto, "New physical method for creating chromosomal aberration," *Nature*, **183:** 905 (1959).
26. D. E. Janes, W. M. Leach, W. A. Mills, R. T. Moore, and M. L. Shore, "Effects of 2450 MHz microwaves on protein synthesis and on chromosomes in the Chinese hamsters," *Non-Ionizing Radiation* **1:** 125 (1959).
27. G. Mickey, "Electromagnetism and its effect on the organism," *N. Y. State J. Med.* **63:** 1935 (1963).
28. J. Heller and G. Mickey, "Nonthermal effects of radio frequency in biological systems," *Digest Internat. Conf. Electronics* **21:** 2 (1961).
29. A. T. Sigler, A. M. Lilienfeld, B. H. Cohen, and J. E. Westlake, "Radiation exposure of parents of children with mongolism (Downs Syndrome)," *John Hopkins Hosp. Bull.* **117:** 374 (1965).
30. "Man's Health and Environment—Some Research Needs." Report of the Task Force on Research Planning in Environmental Health Sciences. U. S. Dept. of Health, Education and Welfare, 1970.

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