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MICROWAVE RADIATION
Its Potential Health Hazards and Their Control

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MICROWAVE RADIATION

Its Potential Health Hazards and Their Control

INTRODUCTION

The main thrust of this microwave seminar – as with any such seminar – is to present and discuss, "What microwave power can do for man." But! We should also look at the flip-side of the coin, that is, "What microwave power can do to man." In this way we can more fully appreciate all aspects of the subject.

Concern over radio frequency hazards has been with us for almost three decades. The earliest, contemporary, human studies [7] were conducted on radar operators during World War II; but, did not detect any apparent physiological changes. In the light of the low power capabilities of the early radar systems it is not particularly surprising that these early studies did not result in any positive findings. It was not, for example, until the early 50's that some cataracts (in humans) were definitely linked with the unrestricted operation of microwave equipment [11]. Later, in the mid-50's, the first microwave death was reported. Dr. McLaughlin's report has had a varied reception, it has been refuted [20], dismissed casually [17], accepted at face-value [23]; while, he continues to hold that virtually unrestricted radar exposure was the causative agent in the worker's death.

Running counterpoint to the scarcity of positive human findings there has been an abundance of animal studies showing definite effects. Some of the animal effects observed have been: formation of lenticular opacities; cerebral edema and hemorrhage; blood changes; chromosomal changes; and, nerve stimulation. References to many of these studies can be found in the bibliographies prepared by: the U. S. Army Environmental Hygiene Agency [29]; and, the University of Rochester Department of Radiation Biology and Biophysics [15]. Prior to discussing the physiological effects of microwave radiation in particular, it is important that we establish a perspective from which to view microwave interactions with matter in general.

NATURE AND MODES OF INTERACTION

Microwave radiation is an electromagnetic radiation and as such has both a magnetic and an electrical field. It occupies (arbitrarily) the position in the electromagnetic spectrum between 300 MHz and 300,000 MHz, this corresponds

to wavelengths of one meter to one millimeter, and an energy per photon of 10^{-6} to 10^{-3} electron volts. (See Figure 1.) The most energetic microwave photon does not have enough energy to rupture a molecular bond – hence, the term non-ionizing radiation. But, we know that heating does occur as well as the rupturing of molecules.

As the electrical and magnetic fields, associated with electromagnetic radiation, penetrate a system, charges within that system attempt to migrate or align themselves with the electric field. At electric power frequencies, and even on up to the lower radio frequencies, little resistance is encountered by the molecules or their distributed charges in their alignment with the changing electric field. Therefore, little work is done by the field and very little energy is extracted by the molecules of the system from the field. With increasing frequency there will be increasing resistance to molecular rotation and charge re-distribution. This resistance will increase to a critical value for a given system; at this frequency the maximum coupling with the field occurs and maximum energy is extracted by the molecules from the field. Under these conditions steric hindrance (i.e. hindrances related to molecular "shape") to molecular rotation may be overcome with the result that molecular bonds will be broken or charge distribution permanently altered, and is probably the principal cause of microwave-induced chromosomal aberrations. As the frequency continues to increase the reluctance for motion outweighs the tendency to follow the changing field. A point is reached at which the molecules cannot follow the field, the field causes no molecular motion, and little energy is coupled out of the beam by the molecules.

As we leave the microwave portion of the spectrum entering the infrared and on through the ultraviolet the system components with which the radiation interacts become smaller and smaller. Fewer molecular interactions are observed, and more and more interactions occur between the field and the tightly bound innermost electrons of the individual atoms. In order for an ultraviolet photon to release an electron from an atom it must be capable of raising the energy level of the electron 30 to 50 electron volts. The categorical term ionizing radiation is applied to radiation which can release electrons from a system. The ultraviolet blends imperceptibly into the portion of the spectrum occupied by x-radiation.

No discussion of microwave hazards would be complete without mentioning the x-ray hazards associated with high voltage electron tubes. This may represent a significant portion of the total health hazard picture. For example, a high-level x-ray field of 300 R/hr was found in the vicinity of a pulsed klystron (duty cycle of 0.0015) when the RF power density at that same location was less than 300 mW/cm^2 [30]. A radiation worker remaining in this field for 0.6 minutes would receive his maximum allowable quarterly exposure. The energy of

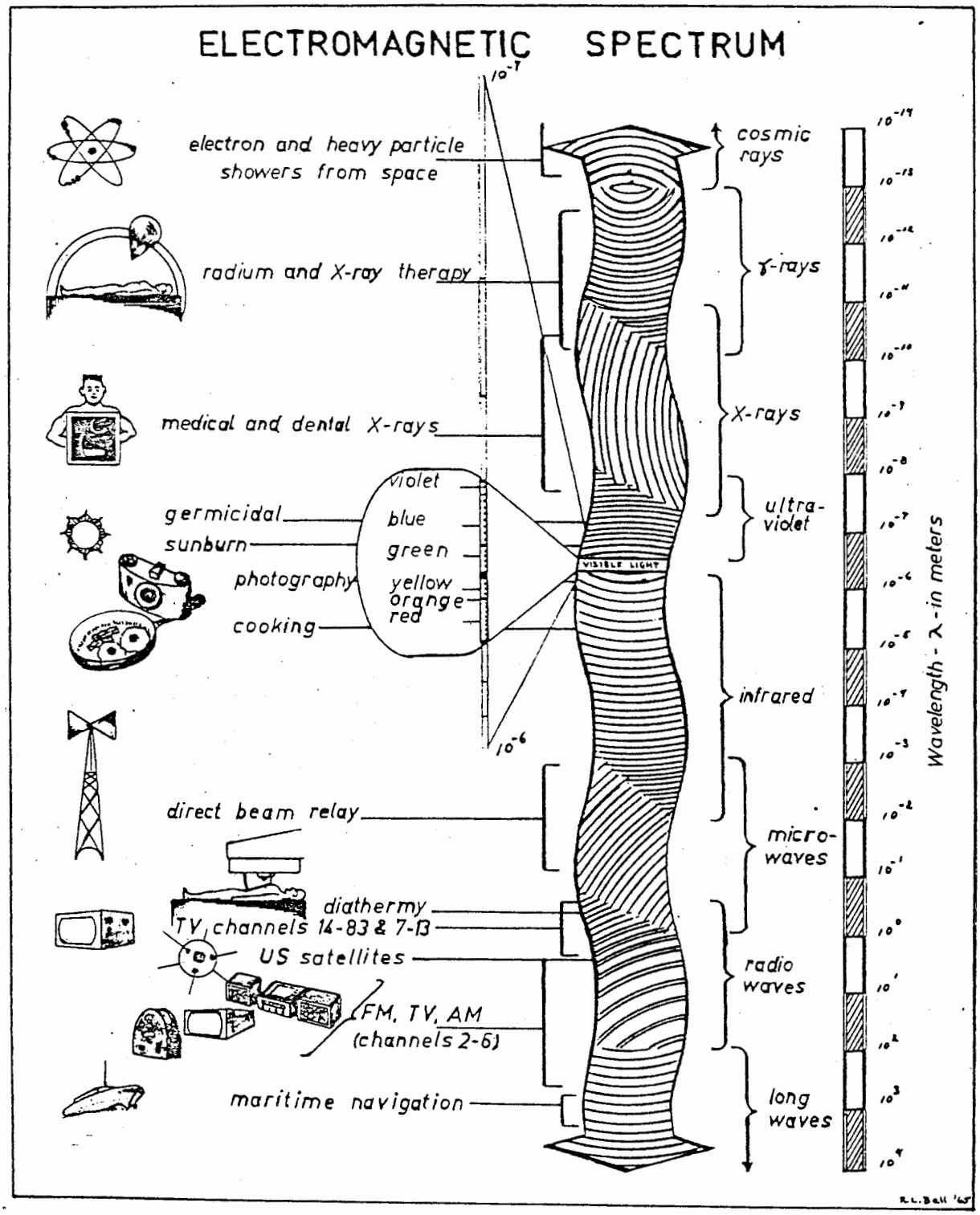


Figure 1–Electromagnetic Spectrum

the x-ray produced (and therefore its penetrating capability) rises sharply with increasing anode voltage [28]. Those involved in the manufacture of microwave generating equipment are aware of the potential x-ray hazard and generally the x-ray shielding provided is adequate. Great care must be taken to insure all shielding is properly replaced after each maintenance operation. The equipment should not be energized until the shielding has been replaced.

An excellent paper by Fanney and Powell [8] attempts to put microwave, infrared, and ultraviolet in their proper relation to each other, particularly, from an instrumentation viewpoint and should be consulted if a discussion of the comparative problems encountered in measuring the different fields is desired.

HUMAN PHYSIOLOGICAL RESPONSE AND INFLUENCING FACTORS

We have not yet determined the exact mode of interaction of microwaves at the cellular level. However, on the molecular level, within the biological tissues, we can make certain definite statements regarding general factors which influence the amount of energy extracted from the field.

- Energy is most completely coupled to a human physiological system between 1000 MHz and 3000 MHz. At these frequencies 20 to 100 percent of the incident energy will be absorbed [20].
- Frequencies well above 3000 MHz are absorbed primarily by the skin. Those frequencies between about 300 MHz and 1000 MHz will penetrate the skin and fat layers to the deep organs where up to 50 percent of the energy is absorbed [13,14,25].
- Periods of exposure, to result in an acute effect, must be of sufficient duration to permit the absorption of a certain minimal amount of energy. Energy required will depend on organ and indication to be observed. A cumulative effect of multiple marginal or sub-marginal exposures has also been predicted or noted by many observers [5,9,10,12,16,19,26].
- Cooling air currents, low environmental temperatures, and lack of fever will all tend to minimize the effect of whole body exposure.
- The spatial relationship of the person to the RF field will have an effect on his physiological response to the exposure. An individual may place himself in a "hot spot" due to the formation of standing waves within the room he occupies. Certain organs may be in highly localized hot spots due to internal reflections, e.g. from fascia [13,14,25].

- The effect upon any individual of a particular RF field is a highly specific matter; we can, at best, predict only the gross effects of group exposures. Just as the sensitivities, to microwave radiation, of organs may vary with water content, blood supply, dielectric constant, and the amount of shielding provided by neighboring organs; the overall sensitivity of a given individual will depend on his build, fat to lean ratio, water content of fat, body temperature, medical history, and general health.

There is hardly an organ or organ system that has not received some attention, as an indicator of microwave exposure; but, the bulk of microwave bio-effects research conducted in the U.S. has concentrated on the eye and in particular its lens.

Cataracts have been observed in many microwave workers since Hirsch's original observation [11]. By May 1965, two individuals at the Air Force Eastern Test Range had been reported to have developed damage to the capsule of the lens after having been exposed to a field known to be greater than 100 mW/cm^2; and, four technicians exhibited eye damage after having been exposed to RF power densities in excess of 20 mW/cm^2 [2]. (For anatomy of human eye see Figure 2.) As of May 1967, Zaret had reported 26 new cases of microwave-induced lenticular damage [16]. Research continues on cataractogenesis, in particular attempts are being made to settle the question of peak power versus average power in the case of pulsed systems. Recent work [1] supports the original view that average power and not peak power is the significant parameter. Some older work suggests there is an upper limit of pulse repetition frequency at which average power is the dominant parameter and from that value on up the biologically effective power level approaches the peak power value. Carpenter has been able to relate RF power density to exposure time and recurrences of exposure necessary to produce lenticular opacities [5]. His tabulated data is shown on page 7.

Testicular damage has been an area of almost as much controversy as the question of radar deaths with all their intrigue. There is ample evidence to support the position that testicular damage does indeed take place; but, there seems to be a polarization of views beyond that, with most operations-oriented observers feeling that any sterility is of a temporary nature while those health-oriented tend to be more cautious [23,24].

Central nervous system effects have been observed but have not yet been made the target of a full-scale U.S. research effort. Many U.S. microwave workers and diathermy patients have reported: headaches, nausea, and ringing in the ears. Soviet scientists extend this list for low-level chronic exposure to include: loss of memory, insomnia, dizziness, irritability, and loss of appetite [16,26].

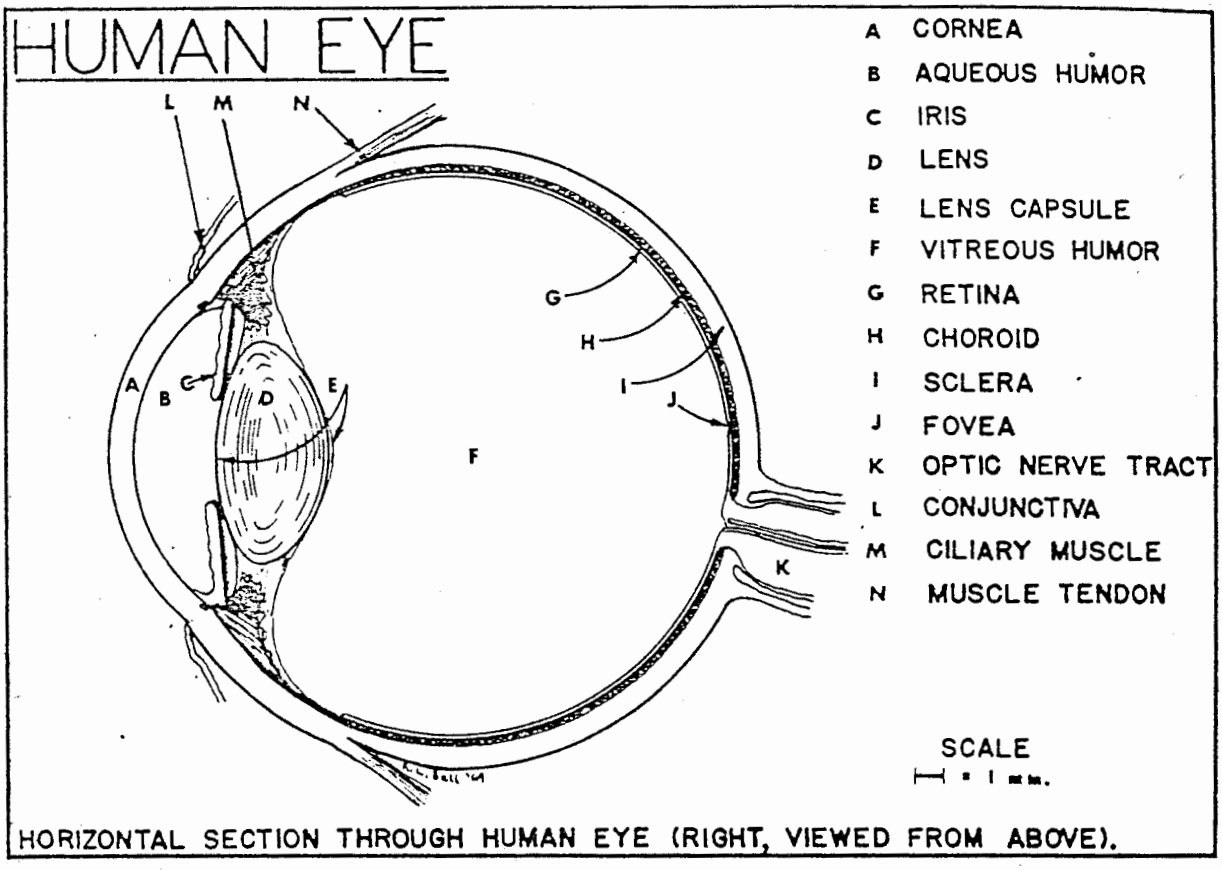


Figure 2–Human Eye

Based upon his observation and accumulation of 115 case histories of chronic and, apparently, at times excessive microwave exposure, McLaughlin [19] has compiled this list of ways in which microwaves may interfere with normal blood clotting:

"1. They (microwaves) set up an inflammatory reaction leading to capillary fragility.

2. They set up a stress reaction and by interference with protein metabolism weaken the walls of the blood vessels.

3. They have an antifibroblastic effect, thus preventing healing of direct and indirect damage to vessel walls.

4. They destroy platelets.

5. They cause inflammation which increases the amount of fibrin and therefore interferes with clot reaction.

6. Fibrinolysis is an undesirable effect of the stress effect of microwaves."

Table 1
Cumulative Effect of Repeated Exposure to
Subthreshold Doses of 2450 MHz Radiation

Power Density mW/cm^2	Single Dose Threshold	Subthreshold Exposures		Number of Exposures at intervals of:					Observed Effects	
		Duration	Ocular Temp.*	1 day	2 days	4 days	7 days	14 days	Opacity	None
280	5 min.	4 min.	48.5°	4					4	4
							4		3	2
							2		2	0
								3	3	5
280	5 min.	3 min.	47.2°	5					7	0
				4					1	1
				3					1	3
				2					2	0
						3			5	0
							5		0	5
120	35 min.	25 min.	44.0°	5					5	0
120	35 min.	30 min.	44.0°		3				4	0
80		60 min.	43.3°	15					3	0
				10					2	0
				1					0	5
40		60 min.		15					0	2

*Temperature in degrees Centigrade recorded in the vitreous body behind the posterior pole of the lens immediately at the termination of the exposure.

Soviet researchers have also noted changes in the blood-picture as well as: cardiovascular disorders; dermographism; loss of appetite; and, changes in cardiac, hepatic, and gastrointestinal function [26].

Little work has been done in the field of human genetics as influenced by microwave exposure. However, there is evidence [16] which suggests an increased incidence of Mongolism in the children whose fathers had previously been exposed to radar. Mongolism is known to be due to the inheritance of an additional chromosome (#21). (For human chromosomal complement see Figure 3.) Generally, the additional chromosome is inherited from the mother. However, cases of Mongolism cannot be distinguished based upon the parent from whom the extra chromosome was inherited.

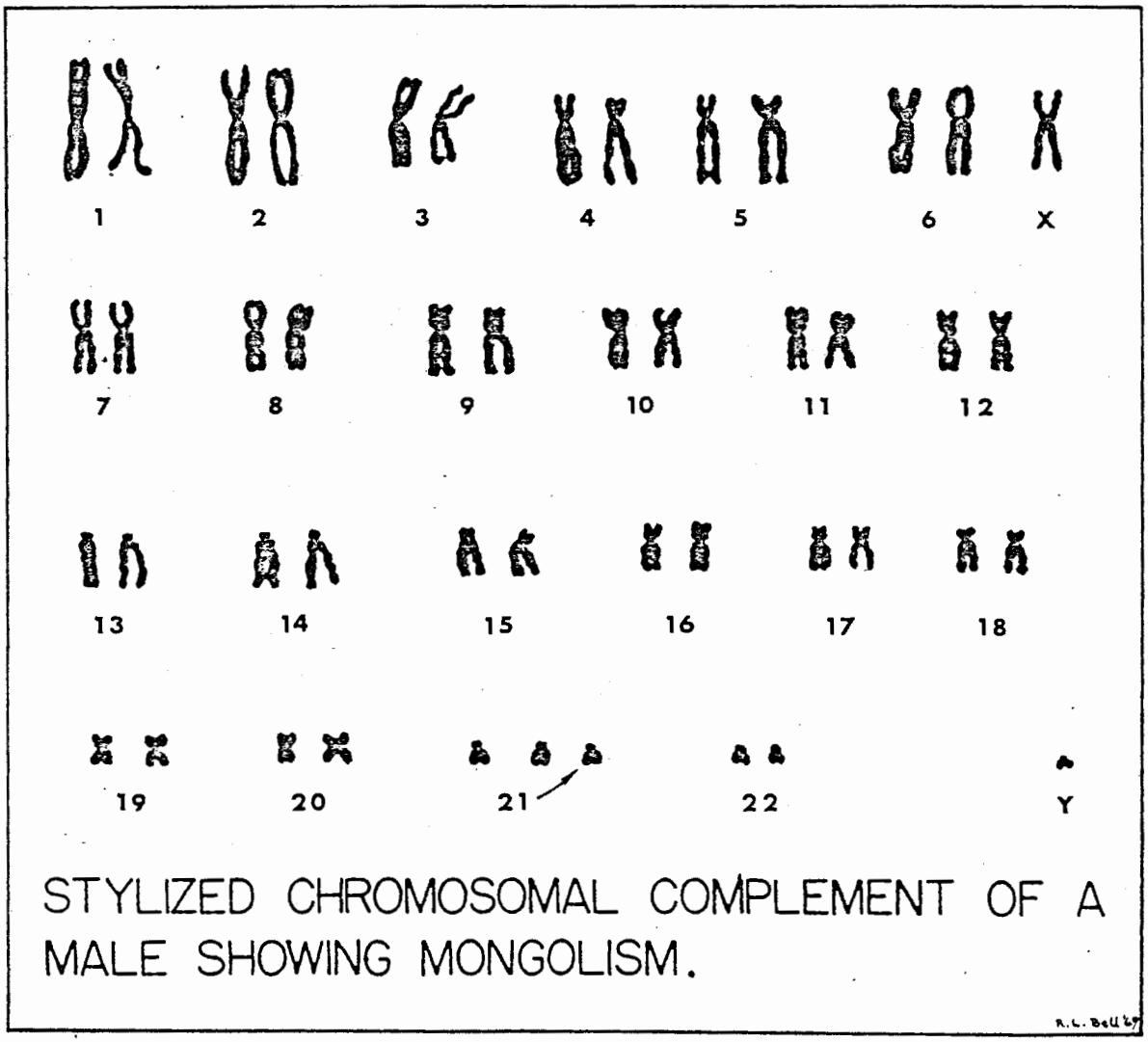
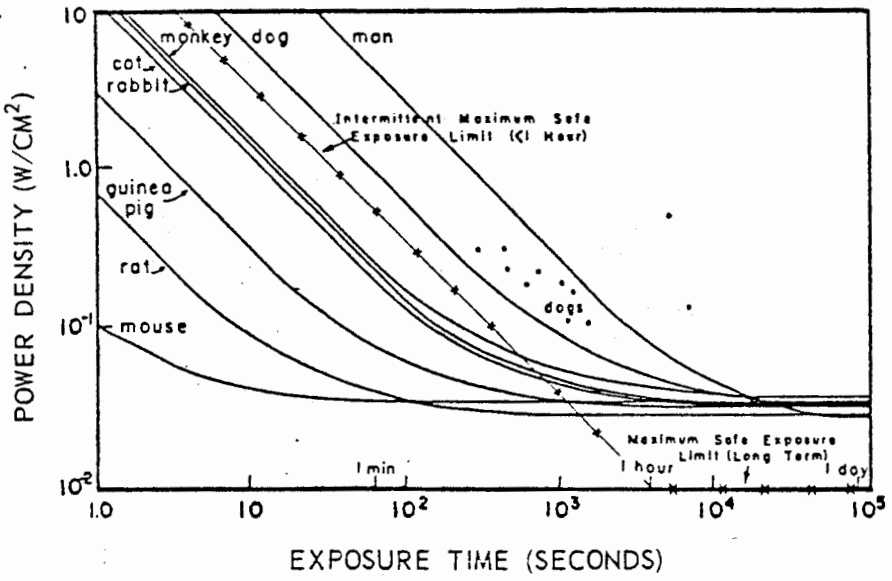


Figure 3–Stylized Chromosomal Complement of a Male Showing Mongolism

The ultimate and irreversible physiological response to microwaves is death. McLaughlin has reported one case [18] in which he determined that microwave radiation was the causative agent, and a case history [19] in which it could very well have been a predisposing factor. For all the controversy there exists about death due to microwave radiation, the fact is that experts disagree on just one point – whether or not it has already happened.

Animal research has been of only qualitative assistance in assessing microwave hazards for humans because there is such a quantitative difference between human response and that of lower animals. The lack of human "biological simulants" [10] and human exposure histories (although, Hoeft has made a fine attempt [12] at relating the exposure of lower animals to man, see Figure 4) is the principal reason so little has been done in establishing limiting values for personnel exposure and enforcing them.



From Hoeft (1965) [12]

Figure 4–Relative Specific Sensitivities to Microwave Radiation

CONSIDERATIONS IN ESTABLISHING A PROTECTION PROGRAM

No longer can an organization using large numbers of relatively low power units or even one high-powered unit afford to be without a microwave health hazard protection program. With the development of the current emphasis on

safety, the american public came to an abrupt awareness of the potential hazards of many of the mechanical and electronic servants it had previously taken for granted. The reaction of Congress to John Q. Public's call for protection was the enactment of Public Law 90-602. The U.S. Public Health Service has been assigned the task of drawing up standards, based on biological response evidence, for exposure of the public as well as workers to radiation emanating from electronic devices – and, microwave and x-ray devices occupy prominent positions at the top of the list. So that there will be a common standard throughout our nation, all states and organizations with experience to draw from are being contacted for assistance in the preparation of the standards. The final result may be more conservative than some of us might at first think. The final standard once in effect becomes the standard of the land and "no State or political subdivision of a State shall have any authority either to establish, or to continue in effect, any standard which is applicable to the same aspect of performance of such product and which is not identical to the Federal standard." [22]

However, despite the apparent complexities of a microwave health hazard program it can in fact be quite simple and straight-forward. An organization which has an internal health physics program or industrial hygiene group, or obtains the services of an outside group to perform those respective functions, has the framework upon which to build its program. A group of specialists performing a staff function with regard to microwave radiation protection is the nucleus of the ideal program. The specialists will first evaluate the current activity and possible growth. The consultation services of the basic group are essential to the optimal fulfillment of the program. Based upon their evaluation they will establish (to a greater or lesser degree of implementation) the following functions:

1. Administrative
2. Occupational Health
3. Training
4. Site Evaluation

The administrative function will include the establishment of standards, review of operating procedures for appropriate radiation protection emphasis, and the establishment of administrative channels and forms to insure the optimum accomplishment of all functions. Most exposure standards in the U.S. are based upon the human body's ability to dissipate heat and the argument that any demonstrable physiological effects due to microwave radiation are thermal in nature. For example, one philosophical approach supporting a 10 mW/cm^2 exposure level may be developed as follows: The heat output of the human body with an average metabolic rate is about 2.5 mW/cm^2, doubling this would be 5 mW/cm^2

over the entire body [25] which intuitively would not seem excessive for the body's cooling capabilities. Since the usual condition would be for the radiation to be uni-directional, only one side of the body would be irradiated. On this basis, doubling the permissible exposure one more time to a final value for unrestricted occupancy of 10 mW/cm^2 seems justified. Remember, this figure has a further safety factor, since it assumes 100 percent absorption of the incident beam and based upon average conditions of exposure 40 percent would come closer to a properly weighted value. However, in calculations involving the health and safety of personnel one must always consider the maximum credible condition.

The value of 10 mW/cm^2 has been accepted generally throughout the industry and the armed services without qualification with regard to frequency, pulsed or continuous transmission, partial or whole body exposure. This value has been further interpreted in two principal ways (graphically represented in Figure 5 [20]):

1. Exposures above 10 mW/cm^2 may be permitted; but, the stay-time decreases exponentially, and no exposure in fields above 100 mW/cm^2 is permitted [27]. Stay-time is calculated from the expression:

$$T = \frac{6000}{W^2}$$

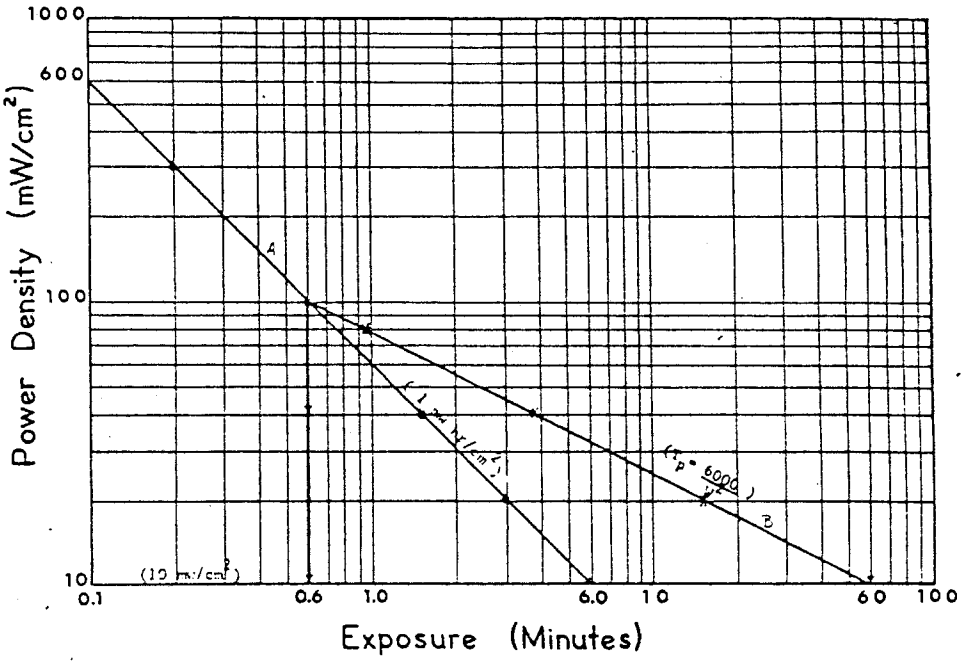
$$W^2 = (\text{power density})^2$$

When "W" is in mW/cm^2; staytime, T, is in minutes in any one hour.

2. The radiation protection guide power density for normal environmental conditions as averaged over any possible 0.1 hour is 10 mW/cm^2. Regardless of the actual period (< 0.1 hour) of exposure or short term power density (recommended upper energy density for any 0.1 hour period is 1 mW hr/cm^2) [4].

In practice the two systems are comparable; although, the military system, which posts an upper power density exposure limit of 100 mW/cm^2, may not be the more conservative when the two views are evaluated in the light of a "biological tissue heat dissipation time constant" comparable in length to the 0:1 hour time period. A comparison of standards or guidelines [17] adopted by various organizations (through 1960) is presented in Figure 6.

The occupational health function of a viable radiation protection program is crucial to both the employee and employer. Prior to exposing an individual to microwave hazards on a routine basis he should be examined by an opthalmologist and a record made of that examination and its findings. No individual should be exposed to microwave hazards if he has certain physiological conditions which

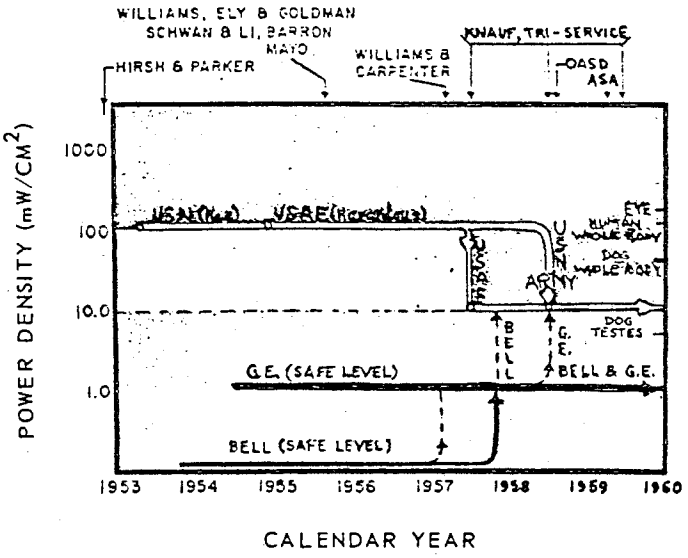


A—USASI, exposure time per 0.1 hour interval

B—USAEHA, exposure time per hour

From Pelmisano and Peczenik [20].

Figure 5—Exposure vs. Power Density



From Mumford (1961) [17].

Figure 6—Recommendation for Safe and Hazardous Levels

could be confused later as evidence of an overexposure. A final opthalmological examination should be made upon termination or transfer. Periodic examinations may be scheduled, or performed whenever overexposure is suspected. A record should be made of all examinations and their results. Such an occupational medicine program benefits both the individual and the organization.

A health hazard protection program must start with knowledgeable personnel. People should be trained to respect a hazard because they are aware of and have a "feel" for what it can do. The operating procedures and manuals are two of the mediums through which a health hazard program is made viable. The consultant will ask himself, "Are the operating manuals currently in use incorporating appropriate radiation protection steps?" If so, "Are the steps flagged as personnel protection measures, and the health and safety consequences of violation spelled out?"

Generally operating procedures or manuals tell the operator exactly what to do and when to do it; and leave out one of the most important ingredients of education – the "why to do it." To include all the "why's" and "wherefore's" would make the manuals bulky volumes indeed (and most of these are spelled out during operator training courses anyway); but, each passage of health and safety significance should be so flagged, and a short statement included concerning the need for the step.

In addition to review and appraisal of procedures as a radiation protection training medium the radiation protection group will provide material and technical support to the supervisor in the field; thereby assisting him in maintaining and upgrading the hazard control training of his personnel. Until a hazards familiarization program package had been developed, queries for information and requests for assistance would be handled on an as-requested-basis.

Because of radio frequency interference problems, as well as requirements for efficiency, only very low levels (significantly less than hazard levels) of RF are allowed to spill over into off-site inhabited areas. This may not be true of buildings occupied by microwave site employees, the walkways between, and the passageways within them. Most sites were constructed so that the original buildings were in mechanical blind-spots of the transmitter; but, subsequent construction may not have always taken this into account. Accordingly, based upon the staff consultant's evaluation of the various installations with regard to peak power, duty cycle, antenna type and size, a determination would be made concerning the degree of hazard from the radiated beam. A decision would then be made with regard to the type of RF measuring equipment required. Those installations with the highest (calculated) potential hazard should be surveyed first; then, each installation in decreasing order of potential hazard should be surveyed. Remember,

even 'though for a particular unit a person might be quite safe standing in front of the dish another person standing in a passageway, near a leaky waveguide coupling, may be in a potentially hazardous area.

An indispensable adjunct to the detection of RF hazards and the entire radiation program concept is the use of appropriate signs and labeling materials. Signs should use the USASI red and black triangle warning symbol [3]. (See Figure 7.) Signs should be designed for maximum flexibility requiring a minimum of alteration for a wide range of field conditions. The signs are the primary method used to warn personnel of radiation levels in excess of the accepted guidelines or areas in which the potential for such fields exists.



RF RADIATION HAZARD WARNING SYMBOL

Color scheme:

Upper triangle — red background

Lower triangle — black background, may include additional warning information

Letters and borders — aluminum

From USASI Standard C95.2-1966 [3].

Figure 7–RF Radiation Hazard Warning Symbol

Prior to the actual site survey there is a significant amount of information available to the consultant which he in turn can provide the site supervisor. For example, the bibliography of references which have been cited in this discussion constitutes a fair sampling of the microwave hazard literature that is available. Some other examples of hazard material available are: "Microwave Radiation Safe Distance Nomogram," Figure 8 [6]; "Maximum Near Field Power Density," Table II [21]; and, "Attenuation Factors (Shielding)," Table III [21].

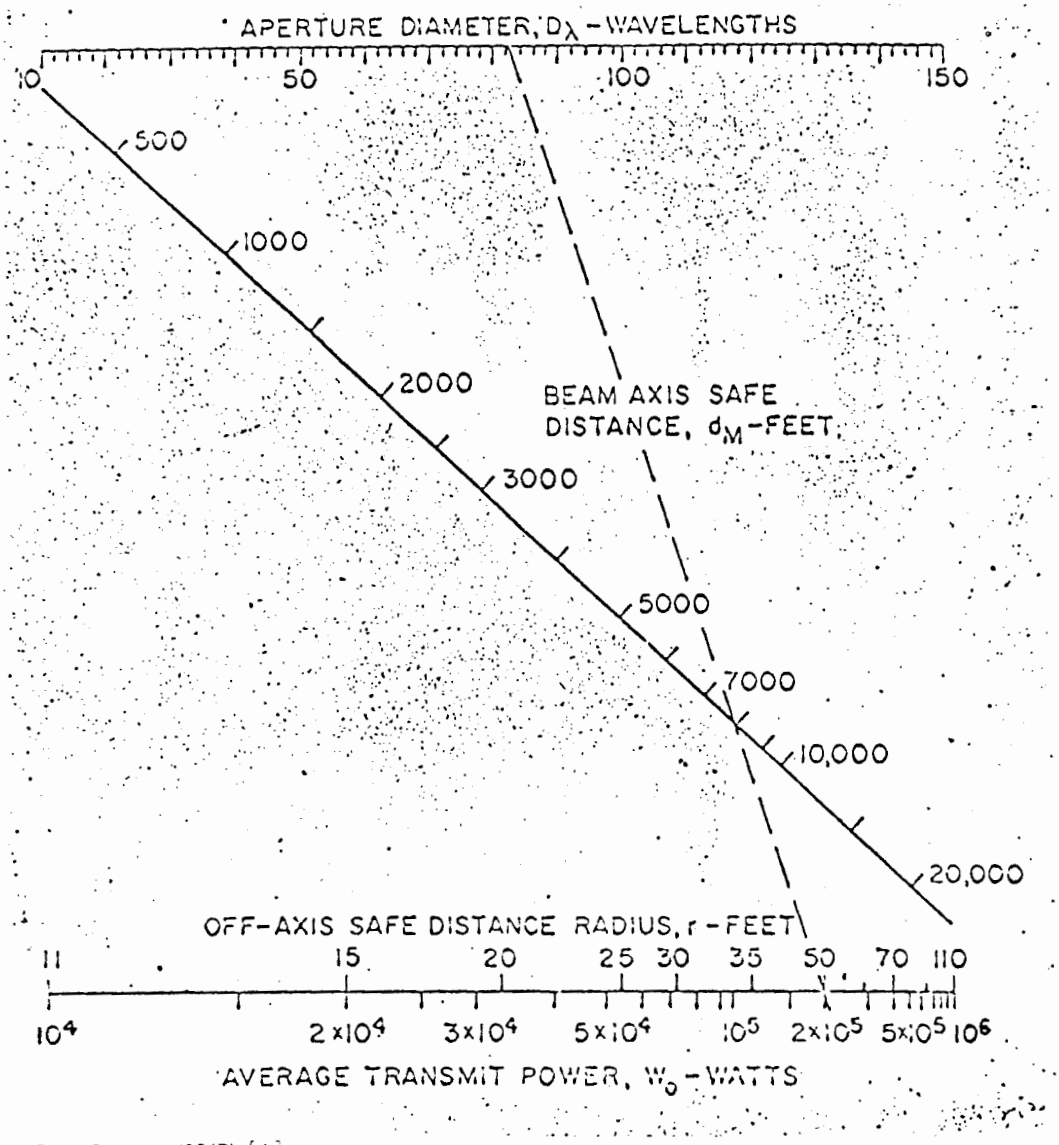
Table II
Maximum Near Field Power Density [21]

Reflector Size (ft.) (Diameter)	$(mW/cm^2)/kW$ of Power
4	341
6	152
8	85.64
10	54.7
12	36.7
15	24.4
30	6.1
40	3.45
60	1.53

Table III
Attenuation Factors (Shielding) [21]

Material	Frequency			
	1-3 GHz	3-5 GHz	5-7 GHz	7-10 GHz
60 × 60 mesh screening	20 dB	25 dB	22 dB	20 dB
32 × 32 mesh screening	18 dB	22 dB	22 dB	18 dB
16 × 16 window screen	18 dB	20 dB	20 dB	22 dB
1/4" mesh (hardware cloth)	18 dB	15 dB	12 dB	10 dB
Window Glass	2 dB	2 dB	3 dB	3.5 dB
3/4" Pine Sheathing	2 dB	2 dB	2 dB	3.5 dB
8" Concrete Block	20 dB	22 dB	26 dB	30 dB

Microwave Radiation Safe Distance
Nomogram
(Based on the standard MSEL of 10 mW/cm^2)



From Cozzens (1967) [6].

Figure 8–Microwave Radiation Safe-Distance Nomogram

The information exchange is a two-way street, and while there are certain areas in which the radiation protection consultant can assist the site supervisor, the entire pre-survey evaluation depends on information supplied by the supervisor e.g. peak power, duty cycle, frequency, minimum elevation at which power is radiated, number of operating personnel, names of those personnel who are required to enter known RF fields, number, type, and function of interlocks, radiation warning system, specific site information.

CONCLUSION

The basic concepts describing the interaction of microwave radiation with matter in general have been discussed; as well as the effect of frequency of the radiation and composition of the system on energy extraction in particular. The types of physiological response by humans was shown to vary from ringing in the ears to death.

A broad-brush treatment of a possible microwave health hazard program was presented and the role of a staff of specialists or consultant service in it. While, in the past, the low power of the older microwave systems was a built-in safety factor, the increasing demands placed upon our capabilities – as man reaches farther and farther out into space – will require breakthroughs in antenna technology as well as increased power output. With increased collimation and power output, and additional biological studies we will be forced to re-evaluate: our personal commitment to personnel safety; program objectives, and risk vs. benefit decisions; and, national as well as international policies and radiation hazard standards, especially with regard to minimum angles of elevation at which power may be radiated. It is going to be more important than ever before to evaluate not only the protection of personnel from microwave hazards per se; but, also the effect of microwave radiation on such items as fuels, explosive initiators, and other electrically operable devices.

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