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THE TRI-SERVICE PROGRAM—A TRIBUTE TO GEORGE M. KNAUF, USAF (MC) (*INVITED PAPER*)

BY

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The Tri-Service Program—A Tribute to George M. Knauf, USAF (MC)

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Abstract—During World War II, the Department of Defense medical services became interested and concerned about possible hazards associated with the development, operation, and maintenance of the increasing numbers of radars and other radio-frequency emitting electronic equipment. After some investigations by the U. S. Navy and the U. S. Air Force, responsibility for research on the biomedical aspects of microwave radiation was delegated in July, 1957, as a tri-service arrangement to Rome Air Development Center, Griffiss Air Force Base, N. Y. Primary responsibility for coordination of the program rested with Dr. George M. Knauf, USAF (MC). The Tri-Service Program included investigation of effects of exposure of the whole-body, selected organs and tissues, single cells, and enzyme systems using various power levels, pulsed and continuous wave, in the frequency spectrum from 200 through 24 500 MHz under acute, subacute, and chronic conditions. The most important contribution of the Tri-Service Program was the validation of the 10-mW/cm^2 safety standard. The Tri-Service Program is to date the only large-scale coordinated effort in the Western world to elucidate and understand some of the basic mechanisms of microwave bioeffects and to assess possible health implications of this form of energy. This paper constitutes an overview of the Tri-Service Program to provide some historical insight into the significance of the program and its contributions to our understanding of the biologic effects of microwaves. The initiative, foresight, and drive of Colonel Knauf was an immeasurable contribution to the success of the program.

Historical Perspective

BEFORE 1956, research on the biological effects of microwave energy was delegated the role of a "stepchild" among other research problems competing for support within the Armed Services. In 1956, however, the Department of Defense assigned to the Air Force the responsibility of tri-service coordination of this research to ensure that all three departments, Army, Navy, and Air Force, would be well informed. To implement this responsibility, the Rome Air Development Center and the Air Research and Development Command Headquarters held a Tri-Service Conference on July 15–16, 1957, to bring together key investigators in the area of microwave bioeffects.

At the time the Tri-Service Program was initiated, a review of existing information on microwave bioeffects indicated the following.

1) Microwave radiation injury had been qualitatively demonstrated in animals but had not been observed clinically in radar personnel.

2) In experimental animals the testes were found to be vulnerable to the shorter wavelengths.

3) Experimentally induced injury appeared to be thermal in nature; i.e., the temperatures induced in the affected regions were sufficiently high to account for injury on a thermal basis.

4) Reliable information on power densities for radar beams in use was not readily available, and the parameters of injurious exposure were unknown [82].

A Tri-Service Ad Hoc Committee was formed in 1958 consisting of military representatives and a number of civilian advisors in the fields of physics, physiology, ophthalmology, microwave engineering, biophysics, and pathology. Representatives from the participating groups met regularly together with the investigators from the various universities, critically analyzed experimental results, made recommendations, and suggested sound approaches to meeting the requirements of the military services. The research program was coordinated by the Rome Air Development Center (RADC); primary responsibility for coordination of the program rested with Colonel Knauf.

Annual Tri-Service Conferences were initiated in 1956 by RADC as the means for reporting to the military services. These annual conferences were attended by key investigators in the field of biological effects and related scientific fields, and by representatives of other interested Government agencies, universities, and industry, to discuss and contribute knowledge towards a better understanding of the biological effects of microwave energy. The findings were reported through the Tri-Service Publications, which represent a valuable data source for investigation of problems related to the field of microwave bioeffects.

In an effort to establish a safe exposure level to microwaves, many variables were considered, such as the frequency of the energy to which an individual might be exposed and the nature of the exposure including time of exposure, field strength, and other aspects. A survey made at the Rome Air Development Center of earlier investigations concluded that the minimum power density[1] for injurious microwave effects was about 0.2 W/cm^2 [65]. Knauf [27] pointed out that the reports which were available concerning tolerance levels for microwave exposure were widely divergent.

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[1] In general the power density referred to in the discussion of hazards and safety standards is the power density present in the absence of an animal or subject.

Sufficient factual data were not available to determine the "safe" exposure level for each frequency throughout the spectrum; therefore, it was decided to select one level satisfactory for all radio frequencies. The accuracy of the methods and instrumentation used was somewhat questionable, and possibly some cases of reported damage were no doubt caused by power densities of approximately 0.1 W/cm^2. Also, the expanded use of electronics equipment had resulted in the addition of microwave energy from incidental sources at many different frequencies. Since it is impractical to measure the power density at each of these frequencies separately, and since the sum of all these assorted RF sources would normally be extremely small, a safety factor of 10 was decided upon, and a safe exposure level of 0.01 W/cm^2 was established [78].

As Colonel Knauf first envisioned it in July 1957, the Tri-Service Program was to include a study of the frequency spectrum from 200 through 24 500 MHz, investigating effects of whole-body exposure on selected organs and tissues, single cells, and enzyme systems using various power levels, pulsed and continuous wave, under conditions of acute, subacute, and chronic exposure.

In summary, the program aimed at attaining the following objectives.

1) Determination of adequate mechanisms, techniques, instrumentation, and information for the protection of personnel from propagating energies when engaged in the development, test, and operational use of military electromagnetic radiation devices.

2) Establishment of valid safety criteria and instrumentation techniques for identifying electromagnetic hazard areas.

3) Formulation of recommendations concerning the means for recognizing the biological effects by medical surveillance.

4) Evaluation of means by which microwave energy may be put to use to serve other military needs.

Research proposals were developed to investigate whether there are effects other than thermal, whether the biological effects are dependent on the frequency of the microwave radiation, and whether there are regions in the frequency spectrum which can be expected to cause specific molecular resonance phenomena in structural elements of the body or possibly cause specific enzyme changes. There was also interest in whether there are "biological windows" in the frequency spectrum or regions of the spectrum which give a more pronounced effect than others or regions which give no effect at all. There was also the desire to discover whether the repetition frequency in pulsed radiation was of any importance from the biological point of view.

The frequencies chosen were 200, 1280, 2450, 2800, 3000, and 10 000 MHz to cover the equipment in use at the time. Investigation at 24 500 MHz was incorporated into the program because of its biological interest in relation to peak absorption.

Work was supported at the following institutions:

1) University of Pennsylvania: to investigate the penetration and thermal dissipation characteristics of microwave energy of 100 to 10 000 MHz in tissues by using phantom models of the human torso;

2) University of Miami: to obtain reliable and detailed information on the effects of 24 500 MHz on whole animals, cells, and enzymes using both CW and pulsed emissions;

3) University of California: to study effects at X-band frequencies (pulsed) on small laboratory animals and on cellular organisms as well as related microwave engineering aspects;

4) State University of Iowa: to investigate the effects of microwave radiation on the brain and hollow viscera of dogs [frequency 2450 MHz (CW)];

5) St. Louis University: to study the physiologic effects of 2450 MHz (CW);

6) University of Rochester: to a) detect and characterize damaging effects of acute and chronic nature in animals exposed to microwaves and b) determine the effect of combined radiation from X-ray similar to that produced by transmitter tubes and microwave sources [frequency 1280, 2800 MHz (pulsed)];

7) University of Buffalo: to study the effects of exposure to to 200 MHz (CW);

8) Tulane University: for the investigation of microwave irradiation on peripheral nerve systems to determine if any neural response can be isolated [frequency 3000 and 10 000 MHz (pulsed)];

9) Tufts University: to determine the effect of microwave radiation on the eyes of rabbits [frequency 2450 and 9100 MHz (CW and pulsed)];

10) New York University: to assess the incidence of lenticular imperfections in radar exposed personnel.

The First Annual Tri-Service Conference on Biological Hazards of Microwave Radiation[2] was held at Griffiss Air Force Base, Rome, N. Y., on July 15–16, 1957. "The very capable and energetic host was Colonel G. M. Knauf, who presided at the sessions and contributed to the success of the meeting by delivering two papers in addition to his appropriate commentaries and introductions [42]." The Second Annual Tri-Service Conference on Biologic Effects of Microwave Energy[3] was held at Griffiss Air Force Base, Rome, N. Y., on July 8–10, 1958. "Colonel Knauf was again the genial host and chairman in addition to presenting three significant papers [42]." The Third Annual Tri-Service

[2] E. G. Pattishall, Ed., *Proc. Tri-Service Conf. Biol. Hazards of Microwave Radiation* (George Washington Univ., Washington, D. C., July 15–16, 1957), ASTIA Doc. AD 11 5603.

[3] E. G. Pattishall and F. W. Banghart, Eds., *Proc. 2nd Annu. Tri-Service Conf. Biol. Effects of Microwave Energy* (University of Virginia, Charlottesville, July 8–10, 1958), ASTIA Doc. AD 131 477.

Conference[4] was held at the University of California, Berkeley, August 25–27, 1959. It should be noted that the data presented at this meeting substantiated the previous choice of 10 mW/cm² for the upper limit of microwave exposure. The Fourth (and last) Tri-Service Conference was held at the New York University Medical Center, August 16–18, 1960. The proceedings of this meeting have been published in book form.[5] Perhaps the singular most important contribution of the Tri-Service Program was the validation of the 10 mW/cm² safety standard.

The following excerpts from the opening remarks by Colonel Knauf at the Second Tri-Service Conference in July 1958 provide the historical perspective of the Tri-Service Program and give eloquent testimony to the foresight of this man and his associates.

> When this program was first conceived at Rome, we limited our thinking to the problem of hazards that might result from exposure to this energy. . . . When we looked at the whole research effort in its new setting it became obvious that it could not any longer be properly called a hazards investigation. We were truly looking at the broad spectrum of possible microwave effects with a view toward being ready should our development people be successful in coming up with the higher power radar they were dreaming about. We dropped the word "hazards" from the title of our effort and replaced it with the word "effects". . . . We first are interested in any possible effect on man which might be produced by the power produced by radiating equipment in use today. Then next we want to get some idea what lies ahead biologically if we continue to increase the power output of our equipment. . . . I think this might be a good time to say that up to date there has not been any effect produced or even hinted at at power levels which remotely approach our established maximum safe exposure level. An effect does not become a hazard until man is exposed to such an effect. . . . It is sufficient to say that the power of this proposed equipment is much greater than anything we have dealt with before. The problem of accidental exposure to this higher power becomes a possibility. The need for protective clothing to cope with certain operating and maintenance problems appears inevitable as does the need for more attention to shielding for buildings and passageways in the operational areas. . . . It is with the thought that we must be ready with answers for the questions that will certainly be asked, that we are going ahead with this forward looking research effort. . . .

A decade has now elapsed since the last Tri-Service Conference was held. The Tri-Service Program and the Tri-Service Conferences served as a landmark in investigations and dissemination of data concerning the biologic effects of microwaves and contributed immensely to our understanding of these effects. After the demise of the Tri-Service Program, coordinated research into the biologic effects of microwaves came to a virtual standstill with very little active research going on in this area in the United States.

The Tri-Service Program

A. Electrical Properties of Living Tissues and Absorption Characteristics of Microwaves

Schwan and his associates at the University of Pennsylvania continued and expanded on their earlier studies of the electrical properties of living tissue and absorption characteristics of microwaves in the body.

All these studies were carried out over a broad frequency spectrum, in some instances from 100 to 10 000 MHz; in others over the total range of radio and radar frequencies from 1 to 10 000 MHz (Table I).

These studies were essential 1) to determine what percentage of airborne radiation is absorbed by the human head, eye, and total body; 2) to judge how deep the radiation penetrates; and 3) to determine how and where the radiant energy is transformed into heat and establishes a major thermal load. Possession of such knowledge makes it possible to state whether head exposure establishes a more serious hazard than the one predicted for the case of "total body" irradiation. It was, furthermore, anticipated that it would be possible to state whether and what frequencies are particularly dangerous for the human eye [61].

This work has been the subject of numerous papers including [4], [5], [56]–[58], [60], [61], [63], [64], and [70].

As a result of these studies, it was determined that on the basis of electrical properties, the tissues of living organisms can be divided into three groups according to their water content: suspensions of cells and protein molecules of liquid consistency (blood, lymph), similar suspensions in a condensed state (muscle, skin, liver, etc.), and tissues with a low water content (fat, bone).

At frequencies of the order of several megahertz, the mechanism of dispersion, due to cell-wall relaxation, is supplemented by the comparatively weaker effects of the relaxation of dipole protein molecules (characteristic frequencies close to 10 MHz) and the structural relaxation of subcellular components [62].

It has been suggested [59], [62] that in the frequency range of 100 MHz to 1 GHz, the electric properties of tissues with a high water content are due to an electrolytic medium containing suspended protein molecules with a lower dielectric constant.

Theoretical investigations by Saito and Schwan [56] indicated that pearl-chain formation is due to the attraction between particles in which dipole changes are induced by the EMF.

[4] C. Susskind, Ed., *Proc. 3rd Annu. Tri-Service Conf. Biol. Hazards of Microwave Radiating Equipments* (University of California, Berkeley, Aug. 25–27, 1959).

[5] M. F. Peyton, Ed., *Proc. 4th Annu. Tri-Service Conf. Biol. Effects of Microwave Radiating Equipments.* New York: Plenum Press, 1961; RADC-TR-60-180.

TABLE I
BIOLOGICAL CHARACTERISTICS OF MICROWAVES

Frequency (MHz)	Wavelength (cm)	Energy (eV—approximate)	Relative Absorption Cross Section Percent[a]			Tolerance Levels (incident power density)
			Fat Thickness (1–3 cm)	Skin Thickness (0.2–0.4 cm)	Body	
400	75	10^{-7}	43–73			
					50–100	0.01 W/cm²
900	33	10^{-6}	51–89			
					20–100	
3000	10	10^{-5}	18–50			0.02 W/cm²
					50	
10 000	3	10^{-4}	41–50			

[a] Adapted from [4].

"Dielectric saturation" in solutions of proteins and other biological macromolecules due to intense EMFs of superhigh frequencies was considered by Schwan [61]. He suggests that such fields cause all the polarized side chains of the macromolecules to become oriented in the direction of the electric lines of force and that this can lead to breakage of hydrogen bonds and other secondary intra- and intermolecular bonds and to alteration of the hydration zone (on which the solubility of molecules depends).

B. 24 000 MHz

The investigations into the effects of 24 000 MHz by Deichmann and his associates at the Uuiversity of Miami School of Medicine are noteworthy; they constitute the only multispecies broad-scale studies available at this frequency. These studies have been reviewed in several publications [11]–[18], [20], [21].

These investigations were performed with a pulsed-modulated magnetron operated at 24 000 MHz (1.25-cm wavelength) with an average power output of 20 W. The studies were designed to determine the biological effects of this type of radiation, utilizing various experimental animals.

Exposure of rats, mice, and chicks indicated that there is an inverse relationship between power density and lethal exposure time (rat and mouse, prone position, total body exposure). For the following power densities (W/cm²), the minimum lethal exposure periods were as follows: (0.15) rats 35 min, mice 5 min; (0.08) rats 56 min, mice 13 min; (0.05) rats 80 min, mice 35 min; (0.03) rats 135 min, mice 140 min.

The local effects produced in the rat were in relation to the severity of exposure and ranged from hyperemia to first, second, or third degree burns.

When compared with continuous exposure (0.30 W/cm²), which killed a rat in 15 min, intermittent exposure to 50 percent of this energy per unit of time over a period of 31 min (generator 1 min on, 1 min off) killed in 16 min of actual exposure time, while 17 percent of the above microwave energy (1 min on, 5 min off) killed in 34 min of actual exposure. These studies suggest that microwave energy might induce subacute or chronic effects possibly for no other reason than prolonged mild hyperpyrexia [13].

The environmental temperature was found to influence the systemic effects of microwave radiation. The period of survival of a rat was more than doubled (from 17.4 to 37.0 min) by a drop in environmental temperature from 35°C (95°F) to 15°C (59°F). A most remarkable prolongation of life was brought about by an effective air volume exchange. Rats exposed continuously to 250 mW/cm² at 15°C lived for 47 min (40 to 63.5 min). Rats exposed similarly but aided in losing microwave-induced heat by air (15°C) from a blower survived for eight to 24 h.

Osborne–Mendel, CFN, and Fischer strain rats showed evidence of leukopenia, lymphopenia, and neutrophilia after 7 h of continuous exposure to 20 mW/cm² with recovery in 1 week. Hematologic recovery occurred in 2 days after 10 min of continuous exposure to 20 mW/cm², or 3 h of continuous exposure to 10 mW/cm². Effects on erythrocytes, hemoglobin, and hematocrit differed in the three strains used. In Osborne–Mendel and CFN rats all values increased; in Fischer rats they decreased [16].

In an ancillary study an attempt was made to determine whether exposure of the testes of rats to microwaves of 1.25-cm wavelength would produce a functional disturbance in the male endocrine system, even though there might be no morphological evidence of damage to the testes [20], [21]. Rat testes were exposed to 250 mW/cm² for 5, 10, and 15 min. This investigation indicated that output of androgen may have been affected.

Deichmann [12] suggests that microwave radiation effects are not directly related only to the level of power density. There are a number of factors involved in determining radiation effects of a certain dose measured in mW/cm². These include the following.

1) Wave length of frequency: absorption increases with reduction in wave length.

2) Time: absorption increases as the duration of exposure is increased.

3) Radiation cycle rate: per unit of time (1 min), the periods of exposure and nonexposure are important, even when the total exposure for this unit of time (1 min) is kept constant.

4) Air motion: with an increase in the velocity of air movement the effects of radiation decrease.

5) Humidity: radiation effects increase with an increase in the humidity.

6) Clothing: in general, radiation effects are more marked in those parts of the body covered by clothing. Certain types of clothing offer protection, acting as a shield or reflector.

7) Environmental temperature: Radiation effects increase with an increase in environmental temperature.

8) Body tissues: injury from a certain dose of radiation can be expected, particularly in organs or tissues with poor blood supply (eyes).

9) Body weight, type, or mass.

10) Position in the field: variables exist because of an exposed subject's position or orientation in the radar beam.

C. 10 000 MHz

At the University of California, Berkeley, investigations were related to the effects of 10 000-MHz microwave radiation on laboratory animals and cellular organisms, the principles and instrumentation problems relating to dosimetry, the hazards to personnel in the vicinity of radiators, the employment of electromagnetic radiation as a tool for biophysical research, and the measurement of the dielectric properties of biological solutions by cavity-perturbation and other methods. This group also studied the effect of intermittent chronic irradiation on the pathophysiology and longevity of the mouse.

Temperature regulation was studied in mice and rats. The trials were carried out partly as continuous long-term irradiation with a low intensity, and partly in the form of intermittent irradiation with intensities varying between 0.009 and 0.438 W/cm^2. The rise in body temperature reached a constant value below the temperature at which death took place when mice were irradiated with an intensity of less than 0.060 W/cm^2. The constant temperature level is a function of the intensity. A constant raised temperature level did not usually occur during exposure of the animals to low intensities, but the body temperature presented a fluctuating curve with rises and falls of short duration. The same phenomenon appeared in normal rats but not in hypophysectomized rats.

The factors which determine the rate of cooling following heating of an experimental animal with microwaves were also studied. The intensity of the radiation in these trials with mice varied between 0.156 and 0.438 W/cm^2. The average rise in temperature was 5°C above the normal body temperature. The rate of cooling was the same in all cases. Irradiation with an intensity of 0.04 W/cm^2 gave a "steady-state" rise in temperature of 2.3°C. A study was also made of the dependence of the effect of previous irradiation on subsequent exposure to microwaves. The initial exposure seems to stimulate the cooling mechanism of the body so that it functions more effectively during the subsequent exposure [51], [71], [72].

In the longevity study, 200 male Swiss Albino mice were exposed to 0.109 W/cm^2 for 4.5 min ($LD_{50}=11.5$ min), producing an average body temperature rise of 3.5°C. The animals were irradiated, 10 at a time, 5 times a week for 59 weeks. Longevity did not appear to be affected by irradiation at this level [52], [73].

Of still more long-term significance were the investigations made at Berkeley on cellular and molecular samples. The first doctoral dissertation to result from the program [81] was concerned with the dielectric properties of water and their role in enzyme–substrate interactions, and was to point the way to extensive bioengineering studies. From the instrumentation viewpoint, perhaps the most important contribution was the development of a cavity-perturbation method of making quick determinations of both real and imaginary components of the dielectric constants of proteins and other lossy materials containing water [74].

D. 3000 MHz

Investigators at Tulane University studied the effect of microwave exposure on growth rate of mice. Preliminary experiments [44] had suggested early decrease followed by increase in growth rate. In later studies, however, in which larger numbers of mice and improved statistical analyses were utilized, it was shown that the growth pattern in mice exposed to 10-cm microwaves, 10 mW/cm^2, 2 min/h each day for 36 days, was no different from that of the controls [6].

E. 2800 MHz

At the University of Rochester, Howland and his associates performed studies to recognize the general biologic responses caused by irradiation from a 2800-MHz pulsed radar unit. This provided baseline data for comparison with studies at other frequencies. Animal response following 1240-MHz pulsed and 200-MHz (CW) exposure was later investigated. The scope of the investigation was extended to include the interaction of microwave and ionizing radiation in mammals.

The results of these studies have been described in several reports and publications: [22], [23], [33], [35]–[41], [68], [69], [75]–[77].

These investigations revealed that animals exposed to microwaves of high power density experience thermal stress. As long as the thermal burden is not excessive, the animal can cope with it. Once it exceeds this level, homeokinetic capability is impaired, and difficulty in

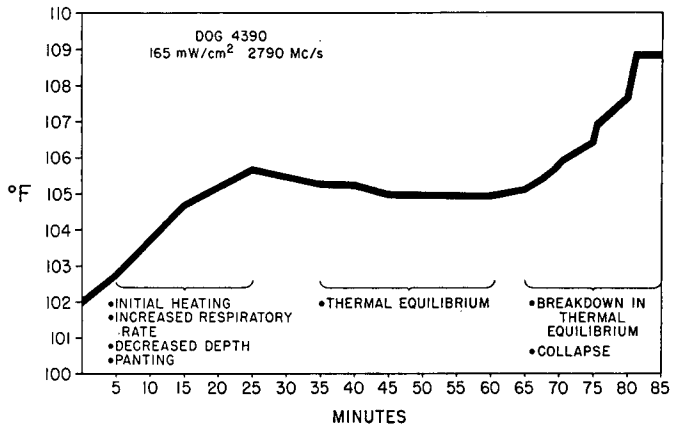

Fig. 1. Response of dog to microwave exposure.

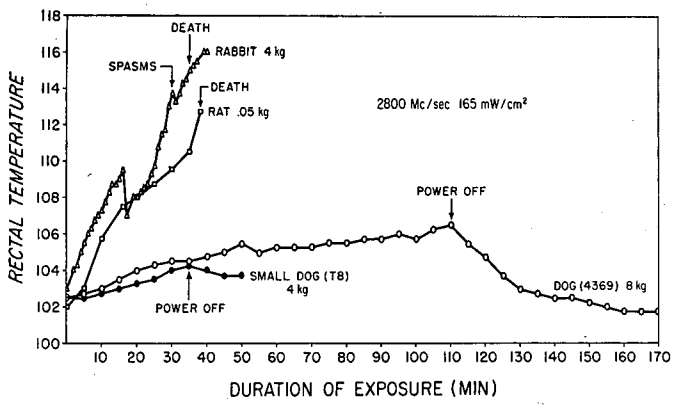

Fig. 2. Thermal response of various species of animals exposed to microwaves.

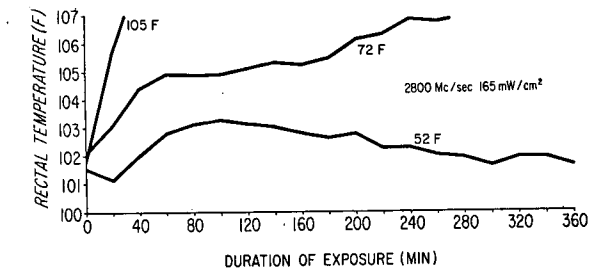

Fig. 3. Response of dogs exposed to microwaves at various environmental temperatures.

maintaining normal function occurs. Superficial or deep burns in various portions of the body, particularly over the thoracic cage, may develop in some dogs.

The thermal response in the dog exposed to 165 mW/cm², 2800-MHz pulsed microwaves at 30-percent humidity consists of three distinct phases. In phase 1, the initial thermal response, body temperature increases by 2–3°F 1/2 h after onset of exposure. In phase 2, the period of thermal equilibrium, rectal temperature stabilizes. This may last 1 h, during which the temperature will cycle between 105° and 106°F. In phase 3, the period of thermal breakdown, the temperature rises above 106°F, and continues increasing rapidly until a critical

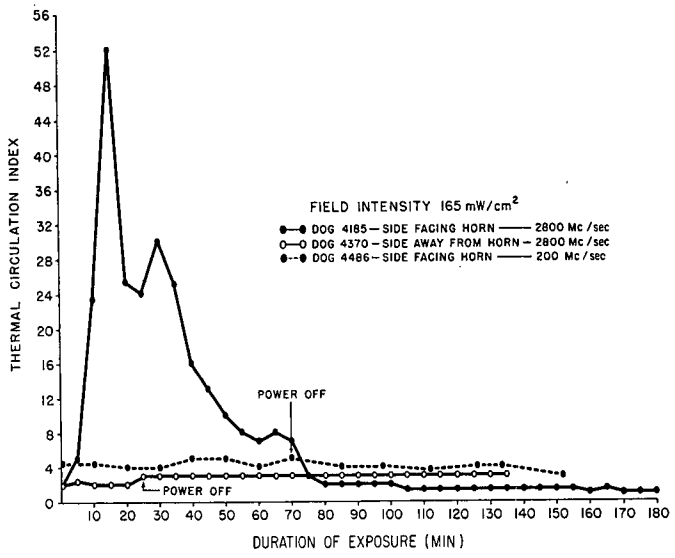

Fig. 4. Thermal circulation index for dogs exposed to microwaves.

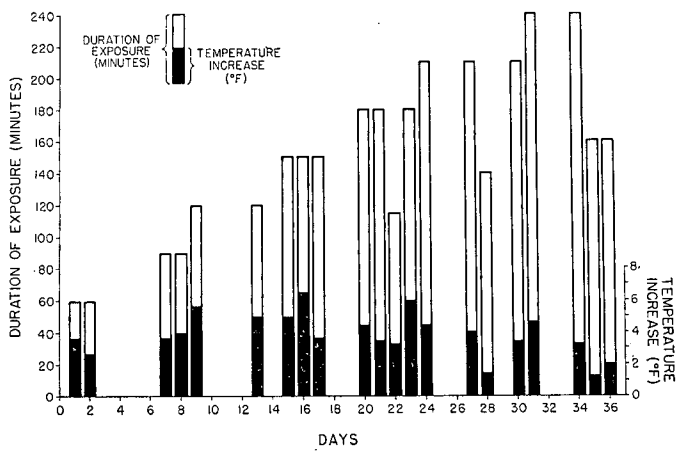

Fig. 5. Development of microwave tolerance at 2800 MHz, 165 mW/cm².

temperature of 107°F, or greater, is reached. If exposure is not stopped, death will occur (Fig. 1).

A critical rectal temperature with no equilibration is reached in 10 min in the rabbit and 20 min in the rat when exposed at 165 mW/cm². The influence of body size on the thermal response at this frequency is negligible. Fox terriers weighing 4 kg, which is equivalent to the weight of the rabbit, respond the same as medium-sized dogs ranging in weight from 8 to 20 kg (Fig. 2).

Exposure of dogs at 100 mW/cm² for periods up to 6 h does not cause a critical rectal temperature. Initial heating is slight, the animal remaining in thermal equilibrium during the remainder of exposure.

Exposure of rabbits at 165 mW/cm² produces an extremely violent reaction. Within 5 min, desperate attempts are made to escape from the cage. Peripheral engorgement of all vessels yields an acrocyanotic picture. Forty min of exposure results in death. When rab-

bits are exposed at 100 mW/cm² for 1 h, they become prostrate.

At 103.5–106°F, 20-percent humidity, thermal regulation is adequate to maintain normal body temperature. Exposure to 2800-MHz microwaves at this environmental temperature results in increased rectal temperature, which is greater than that seen with microwave exposures at 72°F, 30-percent humidity (Fig. 3).

Temperature recovery assumes an exponential form for dogs exposed to 165 mW/cm² or 100 mW/cm². Preexposure level is reached within an hour.

At 2800 MHz the temperature difference between the skin surface of the side facing the radiating source and the rectal temperature in anesthetized dogs diminishes during the initial 30 min of exposure. Thereafter, the temperature of the exposed skin stabilizes while the rectal temperature continues to increase. On the exposed side, the physiologic thermal gradient (difference between skin and rectal temperature) is small while the physiologic thermal gradient on the unexposed side is large (Fig. 4).

Hemodynamic response of the dog exposed to 2800-MHz pulsed resembles that of acute heat stress as manifested by early hemodilution followed by hemoconcentration. As the exposure is prolonged, hemoconcentration becomes more evident.

Dogs exposed at 165 mW/cm² show a body weight loss of 2.0 percent/h. At 100 mW/cm², there is a weight loss of 1.25 percent/h, and hemodilution occurs, as contrasted with hemoconcentration evident at 165 mW/cm².

Leukocyte changes in the dog reflected in distribution of the component cells indicate specific sensitivities related to frequency, power density, and duration of exposure. Lymphocytes and eosinophiles are decreased after 6 h of exposure at 100 mW/cm², 2800 MHz. Total leukocytes and neutrophils are slightly increased at 24 h.

After 2 h of exposure to 165 mW/cm², the total leukocyte count is slightly decreased. When the exposure is prolonged to 3 h, leukocyte increase is observed, which is more pronounced at 24 h. Lymphocyte and eosinophil changes are variable but are decreased immediately or 24 h after exposure.

Dogs anesthetized with sodium pentobarbital or premedicated with chlorpromazine or morphine are more sensitive to the thermal effects of 2800-MHz microwaves than untreated animals.

Repeated exposure to 165 mW/cm², 2800 MHz results in physiologic adaptation as evidenced by the ability to prolong exposure time successively with minimal increase in temperature and progressive depression of "basal" temperature. No overt cumulative effect of microwaves is demonstrated if maintenance of adequate thermal regulation is used as the criterion. Intermittent exposure of the normal animal can be tolerated for extended periods of time and is related to the interval between exposures, which permits the animal time to recover (Fig. 5).

TABLE II

SURVIVAL TIME FOR DOGS THAT RECEIVED IONIZING RADIATION TO THE HEAD

Midline Air Dose (r)		Number of Dogs	Survival Time
25 000	normal	10	22.0 (±1.37)[a] h
	microwave	10	43.1 (±6.70) h
10 000	normal	5	13.8 (±0.73) days
	microwave	5	15.4 (±1.03) days
5 000	normal	5	40.6 (±4.68) days
	microwave	5	43.6 (±15.4) days

[a] Mean (± standard error of the mean).

All animals returned to normal after exposure. Periodic physical and eye examination by slit lamp and ophthalmoscope up to 1 year after exposure failed to reveal any physiologic decrements or lenticular changes.

Latent residual effects of ionizing radiation were revealed by microwave exposure of dogs that had survived ionizing irradiation. This was evidenced by increased susceptibility to the microwave induced hyperthermia. This response indicates a lowered threshold to the stress of microwaves among ionizing radiation survivors and/or inefficient physiologic function in the X-irradiated animal. There was a significant prolongation in survival time among dogs that previously received whole-body microwave exposure when irradiated with 25 000 R of 1000 kVp X-rays to the head. Percent mortality after whole-body X-irradiation of dogs with 1000 kVp X-rays was substantially lower among microwave pretreated dogs than among dogs not previously exposed to microwaves. Simultaneous exposure to pulsed 2800-MHz, 100 mW/cm² microwaves and 250 kVp X-rays, 720 R (2 R/min) resulted in earlier leukocytic recovery from the radiation induced leukopenia. Such enhanced recovery was not observed in comparable exposures at the higher rate of 4.6 R/min (Table II, Fig. 6).

F. 2450 MHz

Investigators at Iowa State University studied the effects of 2450 MHz (CW) microwaves on various biologic systems [24], [67]. One study was to determine whether any functional changes occur in dogs after chronic exposure of the head to 2450 MHz (CW). While the primary purpose was to observe the animals for functional disturbances associated with the exposure to microwaves, an index of temperatures reached at various points in the head and body was also determined.

These studies revealed that temperatures in the cisterna magna, midbrain, frontal lobe, fourth ventricle,

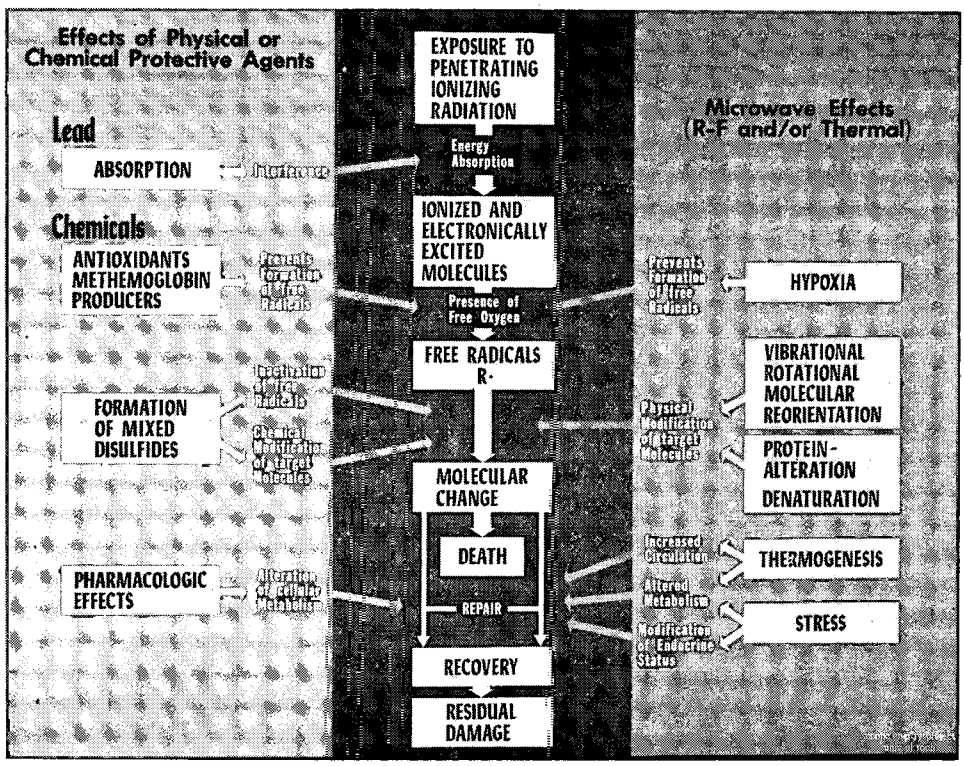

Fig. 6. Modification of sensitivity to ionizing radiation.

and rectum were significantly raised by microwave irradiation of the top of the head in anesthetized dogs. The generator (125-W output) was varied so that the skin damage threshold (42°C) was approached but not exceeded. At no time did the calculated power density exceed 0.8 W/cm² in the center of the field. No gross damage to the brain or its membranes and no clinical evidence of neurologic involvement resulted from either single or repeated 22 periods of exposure. In unanesthetized dogs subjected to a similar pattern of irradiation, the rectal temperature did not rise significantly throughout the exposure, but a panting response was exhibited.

Temperatures were measured in the skin and certain visceral tissues of larger dogs, smaller dogs, and rabbits during two different patterns of microwave exposure. With both of these procedures the amount of temperature developed in the visceral tissues during the exposure was inversely related to animal size, being greatest in the rabbits, next highest in the smaller dogs, and lowest in the larger dogs. It appeared, therefore, that the amount of temperature developed in the visceral organs during microwave irradiation might be a function of animal size as well as duration and intensity of radiation.

Larvae of *Drosophila melanogaster* were exposed to a power density as high as approximately 1.0 W/cm² and induced-heat dissipated. Growth rates during irradiation were not significantly different from control values. When heat was not dissipated, a marked mortality resulted. The results seemed to indicate the absence of nonthermal effects upon the organism.

Richardson [53][6] studied the effect of exposure to 2450-MHz (CW) microwave radiation on body weight in rats. With repeated exposures the animals lost weight immediately after irradiation for a short time, but during periods between exposures they gained weight more rapidly reaching or even surpassing the control level. Lethality occurred in rats exposed to 70 mW/cm² for 15 min.

Richardson [53], [54], was also interested in developing a suitable dosimeter for microwave exposure.

It is of interest to note that Richardson and his associates [55] performed some of the earliest studies on experimental microwave cataractogenesis. Since these studies were not part of the Tri-Service Program, they will not be reviewed in this paper.

The effect of microwave exposure on another biological system characterized by cell differentiation and proliferation was investigated by Van Ummersen [79].[7] All experiments were carried out on chick embryos which had been incubated at 39°C to approximately the 48-h stage of development and exposed to 200–280 mW/cm².

The radiation caused a significant temperature increase in the egg. Abnormalities were produced which included inhibition or retardation of differentiation in the eye, brain, and heart, as well as suppression of development in the posterior regions of the embryos. The allantois failed to develop.

Carpenter [8] suggests two possibilities for microwave

[6] St. Louis University.
[7] Tufts University.

action which should be considered in this investigation: "(1) it may act directly on the differentiating cells, which because of special conditions of their metabolism may be peculiarly susceptible to the radiation; (2) it may affect the environment of the cells and thus alter the organic milieu on which their growth and development depend. In the growing chick embryo, for example, it might alter or perhaps inactivate one or more of the enzymes responsible for metabolism of yolk, the only available source of the energy required for the processes of growth and differentiation."

Since protein denaturation takes place in the neighborhood of 40°C, anything which elevates the temperature to this region could start degeneration of cell structures. The high power densities that were used in this study might be sufficient to cause protein denaturation on a thermal basis. Osborne [47], [48] found that at no stage of development was the chick embryo affected by long exposure to 200-MHz microwaves. In these experiments the temperature rise within the egg was never more than 1°C. One cannot, however, compare 200-MHz with 2450-MHz microwaves in their effects on developing chick embryos because of differences in wavelength and resultant energy absorption by an object the size of a hen's egg.

G. 1240 MHz[8]

Rectal temperature response in dogs exposed to 1240 MHz was comparable to those exposed to 2800 MHz, at similar microwave power densities. The reactions of the animal varied little from the preexposure state until critical rectal temperature level was approached, at which time a moderate increase in panting was noted. The animal appeared comfortable, or slightly agitated. Salivation was normal or slightly increased [40].

While exposed to 1240 MHz, 100 mW/cm², dogs were more relaxed than when exposed to 2800 MHz. Manifestations of a critical rectal temperature (106°F or greater), which were readily apparent at 2800 MHz, were negligible at 1240 MHz. Agitation of the animal was rarely seen. Weakness of the hind quarter was not prominent during exposure but was readily apparent when the animal was removed from the exposure compartment. Panting during exposure at 1240 MHz was less marked than at 2800 MHz.

Daily exposures at 1240 MHz for 6 h/day, 5 days/week, for 4 weeks revealed that at 100 mW/cm² there was an increase in rectal temperature during each exposure for the first week. During the subsequent three weeks, temperature increases were moderate. A progressive lowering of preexposure temperature was evident as the number of exposures was increased. Exposure to 50 mW/cm² initially resulted in slight temperature increase. Progressive lowering of the preexposure temperatures was noted as the exposures were repeated. Exposure to 20 mW/cm² resulted in slight temperature decrease. When compared with sham-exposed dogs, evidence of a thermal regulatory response to the procedure was apparent as the nonirradiated dogs showed a greater decrease in body temperature.

[8] Studies performed by the University of Rochester group.

H. 200 MHz

The uniqueness of these studies performed by Osborne and associates at the University of Buffalo is that they are the only ones of a broad scope performed at this frequency [1]–[3], [47], [48].

Addington *et al.* [2] studied the importance of the position of the body in the microwave field for the occurrence of harmful effects from primary heating. It was found in trials with dogs that the rate and degree of temperature increase was greater when the body was positioned so that its longitudinal axis was parallel to the polarization plane of the microwave field. It was also found that qualititave differences as regards to the form of the head, length of tail, etc., in the animal seemed to be factors in the thermal response.

An approximate median lethal dose for dogs was obtained with 15-min exposure at 330 mW/cm² at perpendicular orientation [3]. Markedly lower lethal rates were produced with slightly longer duration irradiation at 220 and 194 mW/cm², and no deaths resulted from exposures of ½- to 1-h duration at power densities of 165 mW/cm² and less (all at perpendicular polarization). All of the dogs that died had rectal temperature rises of 7.5°F or more. Because of the small number of animals used (37) the data have little statistical significance; however, they give some idea of the range of lethality for 200 MHz.

Studies were also carried out with various lower animals and plants such as protozoa (amoeba, paramecium) worms, flies, bacteria, fungi, etc., with power densities of under 0.04–0.05 W/cm² to find an organism to serve as a standard in microwave irradiation. It was not possible, however, to find an organism which would give a response so unequivocal and reproducible that it could be used for this purpose.

Using the same equipment, the University of Rochester investigators found that at 200 MHz, 165 mW/cm², the dog equilibrates later than at 2800 MHz and remains in thermal equilibrium for a longer period before breakdown. Body size of the animal does not influence response. Equilibration is minimal in the rabbit, and critical rectal temperature occurs within 30 min. Rats exposed for 1 h do not show evidence of thermal breakdown. A dog exposed at 200 MHz, 165 mW/cm² showed little change from its initial thermal circulation index. This difference in thermal circulation index from that which was found with 2800-MHz exposure reflects the difference in depth of microwave energy absorption between 200 MHz and 2800 MHz [40] (Fig. 4).

I. Neural Effects

The group at Tulane University studied the effects of 1.25-, 3.0-, and 10-cm microwave irradiation on the nervous system of both warm- and cold-blooded animals.[9] Experiments were designed to separate thermal from nonthermal neural effects. Refrigerated cold-blooded animals were irradiated with 3-cm microwaves at a power level of 45 mW/cm^2 for various lengths of time. In addition, experiments at the same wavelength and power density were conducted on isolated nerve preparations.

Results from the peripheral nerve experiments indicate that previous reports of neural effects may be explainable as effects due to local heating of peripheral nerves rather than to excitation of the central nervous system [28]. The principal effect observed (viz., increased activity of the experimental animal) was found to be temperature dependent. The most important result of these experiments was that every observed effect of microwaves on isolated nerves can be duplicated by use of convective heat or infrared radiation.

In experiments on steady potentials of the central nervous system (CNS), concurrent rectal temperature measurements indicated a relationship between temperature and the steady potentials. In these experiments measurements were included to develop information on the relation between power and steady-potential measurements in the CNS. Network theory applied to the analysis of measured data provided results reaffirming the reported nonlinear characteristics of neural tissue [19], [43], [45].

The propagation properties of electromagnetic waves in brain material and surrounding tissues described by Nieset *et al.* [46] and Fleming *et al.* [19] showed large values of attenuation for the electric field in the brain and its surrounding tissues of skin, fat, muscle, and bone. Their results indicate a maximum penetration into the brain at about 1000 MHz, with a frequency band of greatest penetration from 300 MHz to 1500 MHz. Much of the incident power is reflected at the lower frequencies while the propagating power is more readily absorbed by the various tissues at higher frequencies.

Nieset *et al.* [46] showed by means of irradiating isolated frog's skin that exposure for 10 to 20 min to 3-cm microwave radiation (0.042 W/cm^2) usually greatly reduced ion transport. It was later found, however, that raising the skin temperature to 38°C usually blocked Na^+ transport.

Pinneo [49] studied direct current potentials of the CNS. The normal brain of the mammal is electrically polarized. Two forms of this steady potential are evident: a "resting" potential present in the absence of stimuli and a second potential that is apparently due to incoming sensory volleys. The importance of these potentials is emphasized by the dc shifts associated with external and locally applied stimulation; these shifts are also intrinsically linked with such phenomena as paroxysmal seizures, spreading depression, and cortical–reticular formation "arousal."

Pinneo *et al.* [50] point out that while peripheral nerves may be thermally activated by absorption of electromagnetic radiation in the 10- to 25-GHz frequency band, CNS structures and systems are effectively shielded at these frequencies by skin, muscle tissue, and skull. Thus, they suggest that frequencies in the range of 400 MHz to 2 GHz be used in the investigation of the effects of microwave energy on neural function.

McAfee [28], [31], using pulsed 3-cm microwave radiation with 1000 pulses per s and an intensity of about 200 mW/cm^2, demonstrated the occurrence of a nociceptive reflex (i.e., a reflex which occasions a movement in the animal to shield or defend itself against harmful influence) in decerebrate cats during microwave radiation. This reflex comprises a sharp rise in blood pressure and pulse frequency, a change in the respiration rate and depth, and movements of the extremities and of the body in decerebrate cats. These symptoms occur when an exposed sciatic, radial, facial, or trigeminus nerve reaches a temperature between 42° and 47°C.

The studies by McAfee [28]–[32] provide convincing evidence that the presumed nonthermal effect of microwaves on the CNS is a result of thermal stimulation of peripheral nervous structures. Studies claiming CNS effects of microwaves should at least include controls for the possible peripheral nervous system effects described by McAfee.

J. Cataracts

Carpenter and his associates at Tufts University carried out some of the most extensive and detailed studies made on the effects of microwaves on the rabbit lens. The radiation source operated at 2450 MHz, CW or pulsed. Except at certain low powers, exposure of the animals was carried out under sodium pentobarbital anesthesia. Measurements were made of the intraocular temperature during exposure. Following irradiation, the eyes were examined regularly by ophthalmoscope and by slit-lamp microscope. In many cases, changes in the appearance of a lens opacity were recorded by stereocolor photography [7], [9].

Carpenter was also interested in comparing the cataractogenic effect of 10 000 MHz [10]. The method of exposure permitted transmission of microwave power directly into an eye which, together with a thin brass iris, formed a waveguide termination.

Lens changes which were observed by the slit-lamp microscope in 136 cases form the basis for Carpenter's threshold curve (Fig. 7). The latency for opacity development was 1 to 6 days after the exposure; the average latent period was 3.5 days [9], [10].

[9] Portions of these studies were also supported by the Veterans Administration Hospital, Radioisotopes Research, New Orleans, La.

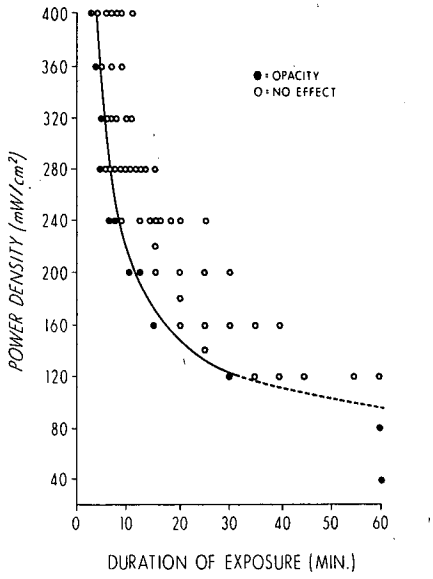

Fig. 7. Time and power thresholds for induction of lens opacities in the rabbit eye from single exposure at 2450 MHz [7], [10].

In further investigations, Carpenter obtained data which he considers as evidence of nonthermal and a cumulative effect of microwaves [7], [9], [10].

At 280 mW/cm² power density the minimal exposure period that caused an opacity was 5 min, by which time the temperature of the vitreous body had risen to 49.3° C. At this power density there was no observable effect on the lens from a 3-min exposure, which raised the vitreous temperature to 47.2°C. However, when the power density was reduced to 120 mW/cm², a 35-min exposure period induced lens opacities while the vitreous temperature was increased to 44°C.

It was also found that rabbits' eyes exposed to 140 mW/cm² with 2450 MHz (CW) for 20 min did not develop opacities, but that rabbits' eyes exposed to 140 mW/cm² pulsed power for 20 min did develop opacities.

Having established threshold cataractogenic exposure periods for the induction of opacities, Carpenter tested the effect upon the lens of repeated exposures of briefer duration than the minimal exposure required for causing an opacity to form. It was reasoned that this procedure should cause less temperature change in the eye than is associated with an exposure at the cataractogenic threshold, and that if any cumulative effect were to occur, it would suggest the operation of some influence other than a thermal one.

It was found that a 4-day interval was not long enough to permit the lens to recover from the damage inflicted upon it by radiation, but that a 7-day interval was sufficiently long for such recovery to take place.

Carpenter has suggested that the cataractogenic effect of radiation may involve "initiation of a chain of events in the lens, the visible and end results of which is an opacity, and that this chain of events must be initiated by an adequate power density acting for a sufficient duration of time if it is to progress to the development of an opacity. If either the power density or the duration of the irradiation are below a certain threshold value, the damage done to the lens is not irreparable and recovery can occur, provided that sufficient time elapses before a second similar episode [9]."

These results do not necessarily indicate a nonthermal cumulative effect. Acute injury of the lens leads first to hydration, and this is reversible providing no lens protein denaturation has taken place despite the fact that banding, striations, and opacification are evident. Hydration of lens fibers may last for many days. If the excess water leaves the lens before denaturation has occurred, no permanent residua results. If another thermal injury intervenes, however, at a time when the lens is partially damaged, there may be a summation of effect [83].

Most investigators agree that there is a critical intraocular temperature which must be reached before opacities develop. This temperature, as reported by various authors, ranges from 45° to 55°C. Obviously, no cumulative rise in temperature can occur if the intervals between exposures exceed the time required for the tissue to return to normal temperature. The cumulative effect to be anticipated, therefore, is the accumulation of damage resulting from repeated exposures, each of which is individually capable of producing some degree of damage [25].

Using 10 000 MHz, eyes were exposed in a "closed system" at five levels of delivered power, from 150 mW/cm² to 1090 mW/cm². At each power exposure times were varied in order to determine thresholds for the induction of lens opacities. Although this threshold curve was similar in shape to that previously shown for 2450 MHz, the power values could not be compared because of their entirely different derivations [10].

The opacities which developed were always in the anterior cortex region. In this respect they were similar to cataracts caused by infrared radiation, which likewise appear typically in the anterior cortex.

Although damage to the lens was not apparent until the second or third day following irradiation, a granular opacity was commonly seen in the cornea in 24 h, but it usually disappeared within four days. Similar results were obtained with 8000-MHz exposure. Exposure at 10 000 MHz in the far field resulted in opacity in the posterior subcapsular cortex of the lens similar to cataracts which resulted when the eye was subjected to 2450-MHz radiation from an antenna in an anechoic chamber. It seemed quite clear, therefore, that in the experiments done at 10 000 MHz, with the "closed" waveguide system, the anterior location of the cataracts was due not to the particular frequency but to the method by which the power was transmitted to the eye [10].

Attempts at a comparison of the cataractogenic relationship of pulsed versus CW radiation were incon-

clusive. Carpenter and Van Ummersen [10] suggested that it would be unwise to ignore the factor pf peak power in assessing pulsed radiation as an ocular hazard.

Van Ummersen and Cogan [80] showed that the age of the animal was not a factor in susceptibility of the lens to damage by microwave power.

In other studies, attempts were made to determine the biochemical changes in lenses of rabbits exposed to 2450 MHz, 280 mW/cm². The duration of exposure was varied depending on the severity of opacification desired [34], [26].

The results of these experiments indicated that the factors which influence the cation distribution of the lens were not particularly sensitive to microwave irradiation. A number of other constituents of the lens were also equally unaffected. The levels of protein, thiol groups, ammonia, glucose, and lactate fell only after an opacity had developed. These results suggested that the first sign of damage of the lens by microwave radiation was the formation of opacities rather than any change in the chemical constituents.

Ascorbic acid and glutathione in the lens appeared to be more sensitive to microwave radiation than any of the other chemical constituents studied. The investigators suggest that ascorbic acid is the most sensitive chemical constituent to be affected by microwave irradiation of the lens.

The University of Rochester group also studied microwave-induced cataractogenesis [40]. In unanesthetized rabbits exposed in the far field to 2800 MHz (CW), lenticular changes in the form of rapid and complete opacification developed after exposure to 220–240 mW/cm² for 1 h. Transient tumescence of the lens fibers was apparent at the lower exposure levels. Daily exposures for short periods did not produce any cumulative effect [69].

Studies of protein metabolism in the lens of rabbits' eyes exposed to 160–170 mW/cm² (2800 MHz, CW) for 30–40 min indicated that the only discernible alteration occurred in the posterior lens capsule. A significant increase in the permeability of the capsule was shown, as well as an impairment in the turnover of labeled sulfate. Studies on protein and nucleic acid metabolism failed to reveal any significant differences between the experimental and control lenses.

Whole-body exposure of dogs to a single treatment of 3-h duration at 2800 MHz (pulsed) microwaves, 165 mW/cm² or for as long as 6 h daily for a 3-week period (2800 MHz, 165 mW/cm²) did not produce any lenticular changes. These animals were examined with a slit-lamp periodically for one year after exposure. It should be pointed out that in these exposures, the dogs could move around freely in their cages and their eyes were never exposed directly to the microwave energy for long periods of time.

In dogs, single or fractionated exposure of the eyes to 2800-MHz (pulsed) microwaves, 350 mW/cm² for 20 min did not cause permanent lenticular alteration. However, single or fractionated exposure of the eyes to 700 mW/cm² at 2800-MHz (pulsed) microwaves for 20 min caused lens opacification which involved the posterior lens capsule and the posterior subcapsular cortex (Fig. 8) [40].

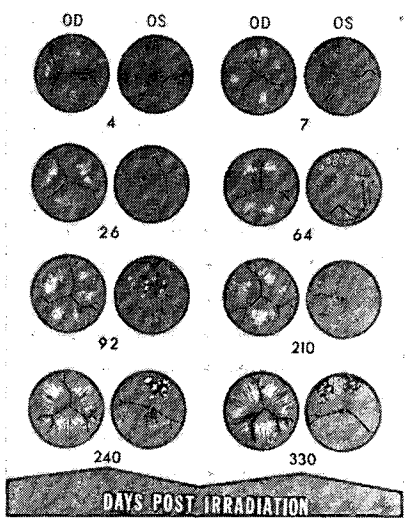

Fig. 8. Lens changes in dogs as a function of post irradiation time; 2800 MHz, 700 mW/cm².

K. Lenticular Effects in Man

These studies by investigators of New York University are no doubt the most extensive performed on individuals exposed to microwaves up to and including the period of the Tri-Service Program.

Zaret *et al.* [86] assessed the frequency of occurrence of lenticular imperfections in the eyes of a sample of 736 microwave workers engaged in installation, operation, and development of microwave equipment and a control sample of 559 individuals of similar age grouping. This study was the first intensive effort undertaken to study the effects of microwave energy on the human eye and to relate ophthalmological findings to actual conditions of exposure.

Analysis of the data revealed that the lenses of both microwave workers and controls had defects and that the number of defects increase linearly with age. Although there was an apparent statistical difference in eye score between the exposed and control groups, the difference was demonstrated to be clinically insignificant. The extent of minor lenticular imperfection does not serve as a clinically useful indicator of cumulative exposure to microwave radiation. No relationship between lens imperfection and microwave cataract was found. A peculiar finding was that the difference in eye scores appeared to be constant for all age groups. The clinical impression gained from the detailed microscopic lenticular examinations was that the defects present in the lens are not generally an indicator of cumulative chronic exposure to RF radiation. However, the effect of microwave exposure was demonstrable by standard statistical treatment of the data.

It was determined that irreversible injury to the human lens can occur when the magnitude of exposure reaches levels of several hundred milliwatts per square

centimeter and there are multiple exposures at least of several minutes duration. Continuous exposure to permissible levels of microwave radiation (10 mW/cm²) did not appear to have any significant clinical effect on the human lens insofar as the sample studies appeared to indicate.

It was also noted that exposures to levels of microwave radiation in excess of 10 mW/cm² but below 300 mW/cm² may produce reversible injury of the lens. This condition is termed intumescence and is recognized as a swelling of the lens and it is probably due to hydration.

An important aspect of this study was the determination that, in areas where accepted safety practices were observed, microwave workers did not reveal lenticular changes significantly different from those exhibited by an unexposed or "control" population. The etiology of microwave cataract appears to be of a thermal nature [86].

This study had additional implications for the conduct of follow-on animal research. For example, it was shown that small lenticular imperfections such as granules, vacuoles, and minute opacities are not necessarily precursors of damaging microwave effects. The observation that marked species differences exist with respect to the type location and induced lenticular injuries imposed the additional requirement that both criteria and examination techniques demonstrate the feasibility of extrapolating animal data to man [84]–[86].

Epilog

For those of us who participated in the exciting days of the Tri-Service Program, we can only look back with a feeling of nostalgia and respect for the stimulus which Colonel Knauf provided in his sometimes authoritative, but always congenial manner. Although the Tri-Service Program has been criticized for the lack of quantitative data produced, one must not lose sight of the fact that this program was the only large-scale coordinated effort in the Western world to elucidate and understand some of the basic mechanisms of microwave bioeffects and to assess possible health implications of this form of energy. It must be realized that, at the time the studies were initiated, the art of microwave dosimetry was just emerging. Also of great importance is the fact that there were very few groups available at the time that were oriented toward the type of study required for elucidation of microwave bioeffects. Any thorough and objective review of the proceedings of the Tri-Service Conferences reveals the wealth of information that became available in the short period during which this program was in effect.

We have had a chance to look back and reflect on the results of the Tri-Service Program, the period of apathy since the Tri-Service Program ceased, and the recent resurgence of interest in the question of microwave hazards since the enactment of Public Law 90-602 in October 1968. We should now be in a better position than ever to engage in productive investigations into the biologic effects of microwaves based on well-designed, adequately controlled, conceptually valid investigations in this obviously growing and very important field of microwave bioeffects investigation. We can appreciate the remarks made by Colonel Knauf at the Second Tri-Service Conference in July 1958, which are as pertinent today as they were twelve years ago:

> You must remember that this subject has an enormous public appeal and lends itself readily to sensational headlines in the press. I know. We are presenting the whole story honestly and factually in keeping with our promise of last year. This is done because we feel that a technical group such as this will be able to accurately interpret the results of our work in terms of hazards. We feel this group represents the folks who have a need to know what we are learning. This might be looked upon as a report to the stockholders.

Appendix

George M. Knauf, M.D.

Dr. George M. Knauf was born in Camden, N. J., October 17, 1906. He received the B.S. degree from the Hahnemann College of Science in 1930 and the degree of Doctor of Medicine from the Hahnemann Medical College, Philadelphia, Pa., in 1934. After a rotating internship, Dr. Knauf entered the private practice of medicine in 1935 at Rising Sun, Md. He continued in private practice until he entered the military service in 1940.

In the military service Dr. Knauf was assigned a wide variety of military medical duties during the period from 1940 until 1952. These duties included such assignments as Wing Surgeon, Hospital Commander, and Center Surgeon both in this country and overseas. Following a tour in the Far East during the Korean hostilities, Dr. Knauf was assigned to duty at the Rome Air Development Center. Here he occupied two positions, one as Base Surgeon and the other as Deputy Director of Technical Services in the Electronics Research Center. In this latter capacity he was responsible for the Tri-Service Program.

George Knauf in his enthusiastic, convincing, tireless, and friendly personal way, brought together and stimulated a group of investigators which included engineers, physicists, physicians, physiologists, and pharmacologists. He helped each investigator to organize his own group of technical experts, paved the way, when paving was needed, to expedite the project, and never was too busy to make the rounds at the institutions involved for the purpose of correlating data or answering questions. All of us who got to know George, and who had the coffee pot always ready whenever he appeared on the scene, know the role that he played in putting microwave radiation research on a sound basis and in separating microwave fiction from facts.

It was he who was largely responsible for the organization of the Tri-Service Conferences, which brought the research teams into intimate contact with the military—conferences which met at Rome, N. Y., in 1957

and 1958, in Berkeley, Calif., in 1959, and in New York, N. Y., in 1960. The research carried out during approximately ten years resulted in the establishment of the current standard accepted in the United States and abroad.

In September 1958, Colonel George Knauf was reassigned to the Air Force Missile Test Center at Patrick Air Force Base, Fla. for duty as Center Surgeon. Here, his responsibilities included the supervision of a broad industrial medical program associated with problems resulting from missile and booster launch operations. He organized and conducted courses of instruction in the "Medical Aspects of Missile Operations," for medical service officers of all three medical departments.

Shortly after the activation of Project Mercury by the newly formed NASA, he was appointed Assistant for Bioastronautics to the Department of Defense Representative for Project Mercury Support and charged with responsibility for all DOD medical support of Project Mercury Space Flight Operations. In January 1962, Colonel Knauf was detailed to NASA to serve as the Deputy Director, Space Medicine, Manned Space Flight.

On October 31, 1962, Colonel Knauf retired from the Air Force, and immediately accepted an appointment to the same NASA position as a civilian. In May 1963, Dr. Knauf was appointed Acting Director, Space Medicine. In this capacity his major contributions were coordination of the NASA Space Medicine Program with Air Force and other DOD elements, provision of medical administrative guidance and council to the Directors of Manned Space Flight Centers, recognition of NASA's overall medical needs, and the establishment of finite program definition between the life science elements of manned space flight and advanced research and technology.

On December 31, 1964, Colonel G. Knauf resigned his position with NASA and accepted a position with the Boeing Company, Seattle, Wash., as Chief, Aeromedical Support for the Boeing Supersonic Transport Branch. In this assignment he reviewed the SST program at Boeing to identify aeromedical considerations which could influence the design of the aircraft. He also worked closely with special airline and Federal Aviation Administration committees assigned to investigate the aeromedical aspects of the U.S. SST design.

George Knauf passed away on June 12, 1968, after suffering an acute illness.

George was a proud man; he was sincere and honest; he was dynamic and a tireless individual whose driving force and enthusiasm for assigned duties and tasks flowed over and influenced and stimulated those around him. The world has become a better one because of his contributions to mankind. Those of us who had the privilege of working with him shall never forget him.

WILLIAM B. DEICHMANN[10]

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