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THE BIOLOGICAL EFFECTS OF ELECTRO MAGNETIC RADIATION (HERTZIAN WAVES)

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CHAPTER I

THE PHYSICAL NATURE OF ELECTROMAGNETIC RADIATION

The Electromagnetic Spectrum

The existence of radiations outside the visible spectrum was first demonstrated by Sir William Herschel in 1800 when he found that a thermometer showed a higher temperature when placed in the red end of the spectrum than it did in the blue end and a yet higher temperature when beyond the red end. Two years later, Ritter and Wollaston independently proved the existence of rays beyond the violet end of the spectrum by establishing that the chemical action of light on silver chloride was even stronger in those rays than in the visible violet.

H. Hertz, in 1888, demonstrated that the electromagnetic waves, which he was first to generate, had all the properties of ordinary light, i.e. reflection, refraction, diffraction and interference. Numerous other workers subsequently added considerable proof to this concept. The group of frequencies, which are now referred to as Hertzian waves, are the longest of the electromagnetic radiations, falling in the class below infra-red, visible light, ultraviolet, X-rays and gamma radiation in that order of decreasing wavelength or increasing frequency.

According to the Encyclopaedia Britannica (18 880 1949 Edition) "Corresponding to the wide range of wave lengths in the electromagnetic wave spectrum, there is a range of generators of widely different sizes. Long Hertzian waves are generated by systems having large inductances and condensers. Very short Hertzian waves are generated by an oscillator consisting of two minute metal electrodes. Then there are systems of vibrating molecules in crystals, and in solid bodies in general, which generate radiation by virtue of their thermal motion. Changes of vibrational and rotational energy of molecules produce radiation in the infra-red. At shorter wave lengths, electronic transitions within the atom itself come into play, transitions of outer electrons producing the optical spectra and transitions of the inner electrons, the X-ray spectra. Then for the production of gamma rays transitions within the nucleus come into play."

At the present time, the standard radio broadcast band extends from about 550 Kc. to 1500 Kc. The so-called shortwave radio bands extend from about 1 Mc. to approximately 50 Mc.; the F.M. and television bands
300
are in the order of 100 Mc.; radar extends upward as

high as and beyond 9000 Mc.

It is interesting to note, following the discovery by D'Arsonval in 1880, that the frequencies above 5000 cps. (.005 Mc) produced no muscular contractions in experimental subjects as did the lower frequencies, but rather a sensation of heat. The spark-gap diathermy was first used for the production of tissue heat. It operated on a frequency of about 1 Mc. After the vacuum tube was invented, higher frequencies were made possible so in the third decade of this century, the short wave diathermy using frequencies ranging from 5 to 50 Mc. became the vogue. It was not until World War II that much higher frequencies became available, and that development was due to the invention of the so-called magnetron which was capable of producing frequencies as high as 9000 Mc. This new device was and is the "Heart" of radar. It is now the essential part of the so-called "Microtherm," a generator which is used to produce localized tissue hyperthermia therapeutically.

<u>Absorption of Hertzian Waves</u>

The interaction of radiation and matter has been the subject of considerable investigation since the time of Maxwell who propounded a theory that in metals the higher the conductivity, the greater the coefficient of absorption. From this theory it follows that perfect dielectrics should be perfectly transparent to Hertzian waves, which, therefore would not be absorbed by the dielectric. Thus, a relationship can be worked out in terms of conductivity and the dielectric constant, which will describe and define the absorption.

Other interesting theories have been advanced, one by P. Drude[140] who attempted to explain the measured increased absorption over the calculated of many organic substances, especially those containing hydroxyl groups, as due to the presence of resonators with a large damping coefficient. A more promising theory was that of Debye[139-140] who attributed this behavior to the presence of dipoles in the molecules which tend to set themselves in the direction of the electric force. Thus, in a rapidly alternating electromagnetic field the rapid rotational motion of oscillations of ions will tend to produce why may be thought of as friction and would thereby dissipate the energy as heat. This phenomenon is known as dielectric hysteresis, a rather crude analogy of which is the production of heat in a rubber tube which is repeatedly stretched and relaxed at a rapid rate.

Certain mathematical relationships have been set up which describe these properties of conductivity, dielectric constant and the frequency of radiation.

Thus:

$$K = \frac{\nu \epsilon}{2}$$

K = Conductivity (Absolute Units)

ν = Frequency

ϵ = Dielectric constant of the specimen

Schereschewsky[120] in 1933 reported the experimental determinations of the dielectric constants in certain tissues of the rat as follows:

Brain	78.54
Liver	75.95
Spleen	77.6
Muscle	77.6
Kidney	76.2
Kidney fat	13.6

Breitweiser[16] reported the dielectric constant of Blood serum to be 85.5 and that of protein 85.0.

The frequency of radiation in this relationship refers theoretically, of course, to the frequency of optimum heat production in tissues or other matter with respect to their conductivity and dielectric properties.

The dielectric constants of a given tissue vary with the frequency, but the results of any such determinations have been incomplete and few have been performed. One such investigation is being done at present by Herrick[57] et al at microwave (2450 Mc.) frequencies, in an effort to verify experimentally observed temperature distributions in various tissues.

The radical variation of physiological effects with wavelength has recently been pointed out by Salisbury[118] et al both from experimental work and certain theoretical considerations. These differences were ascribed to the variation in loss factor of the body with wavelength. "At longer wavelengths where the loss factor is relatively low the temperature of the whole body is raised, giving rise to artificial fever and to a sensation of warmth but with little danger of tissue damage. At extremely high frequencies the loss factor is relatively high and energy is largely absorbed near the surface. This may cause severe surface burns, but ordinarily the sensation of pain will give ample warning in such cases." Mathematically this is explained in the following manner: "A plane wave of electromagnetic radiation falls upon an idealized animal, assumed to be a homogeneous dissipative medium. The energy density in the electromagnetic field a distance "x" below the surface of the animal is:

$$E = E_0 e^{-\alpha x} \quad (1)$$

where E_0 is the energy density (measured in watts per square centimer) at the surface and α is the attenuation constant of the medium. Since α is the fraction of the energy removed from the beam in one centimeter, the energy transferred to the medium as heat is just α times the energy density at the point in question. This transfer of energy from the beam of electromagnetic radiation to heat in the tissue is assumed to be solely due to dielectric heating. Let us define $H(x)$ as the number of watts per cubic centimeter of heat energy transferred from the beam to the medium. Then

$$H(x) = \alpha E(x) - E_0 e^{-\alpha x} \quad (2)$$

It is well known that the loss factor and hence the attenuation constance of most materials increases with frequency * * * * *."

"The temperature rise caused by a distribution of heat --- depends entirely upon the cooling of the medium. In the absence of any cooling, the temperature at any point, $T(x)$, will be proportional to the total number of joules of energy that has been put into the medium at the point "x". That is

$$T(x) = CH(x)t \qquad (3)$$

where C is the thermal capacity ver unit volume of the medium and t is the time of exposure. So in this case the shape of the temperature function is the same as that of the heat function."

Experimentally these concepts are rather well borne out in studies made on rabbit eyes. Cataracts in the eyes of these rabbits were produced when the field intensity was of the order of 3 watts per square centimeter at wavelengths of 12 cm and the duration of exposure was 10 minutes.

During the late 3rd and early 4th decade of this century there was considerable controversy over the question of specific effects of shortwave radiation, other than thermal.

The consensus of opinion after many experiments designed to prove or disprove the theory of specific or athermic effects of h-f radiation is that all observed physical and pathological changes in biological tissues can be explained by the effect of heat alone.

Another concept, that of "point heating" and specific heating has been advanced. This concept logically follows from the relationship of conductivity and dielectric properties to the frequency. It has been pointed out from the work of Schereschewsky that the dielectric constant, for example, of fat as compared to that of muscle tissue for a given frequency are quite different and, consequently, the amount of heat produced would vary considerably depending on the frequency. This fact has been well borne out by many investigations in a rough qualitative manner. The difficulty of comparing results lies in the inability to the present day to devise generators, modes of exposure, and dosage measuring devices which are designed to accurately measure the incident energy as well as the energy absorption of the experimental tissue. However, it seems reasonable to presume that every tissue has an optimum heating frequency. Because of the comparatively efficient heat regulation and distribution system of the mammalian body, the practicability of utilizing specific frequencies to heat specific tissues at the exclusion of other adjacent tissue is doubtful.

CHAPTER II

ACTION OF HERTZIAN WAVES ON VARIOUS BIOLOGICAL AND BIOLOGICAL-LIKE SUBSTANCES

Non-living, organic and inorganic substances

The rate of heating of a solution of sodium chloride depends upon its concentration, and therefore its conductivity or dielectric constant, and the frequency of the radiation to which it is exposed. A 0.05% solution of NaCl heats most rapidly at a frequency of 25 Mc whereas that of a concentration of[62] 0.025% heats most rapidly at a frequency of 10 Mc. If one extrapolates[97] the data of these and other similar data he will find that a solution with a concentration of normal physiological saline should have its greatest rate of heating at a frequency of about 300 Mc.

The relative heating of various biological materials varies with different frequencies as well[120] as with the material itself. In one investigation with eight different frequencies between 64 Mc and 300 Mc in which the heating of blood serum was the standard to which the heating of all the other tissues was referred, it was found that the heating of various organs and the tissues showed the greatest differences at the lower frequencies. At the frequency of 300 Mc the heating became relatively more uniform, although lung and brain tissue showed a greater tendency to heat than did blood serum. In another investigation[2] a frequency of 60 Mc revealed a relative heating in the following descending order: fat, bone marrow, bone, lung, skin, spleen, liver, hair, brain, muscle. Blood corpuscles were heated more, and blood serum less than whole blood.

Botanical structures

Various types of plant tumors when subjected to massive exposures of radiations of 150 Mc demonstrated an acceleration in growth followed by death.[49]

Bacteria and unicellular organisms

In an attempt to demonstrate the effects of these high frequency currents, other than that of the heat factor, investigations were done under conditions intended to control this factor.[95] One such series was performed in which diphtheria toxin was chilled in ice water at 7°C and then exposed to radiation until the temperature had risen to 38-40°C, rechilled, and then re-exposed for a total exposure time of 15-60 minutes. The controls were heated to the same heat in a conventional manner. Another series was done by maintaining a constant temperature during exposure. It was concluded that there was an attenuation of the toxin if the temperature of the toxin were allowed to go above 18°C. The frequency used was 158 Mc.

When cultures of living virulent tubercle bacilli were irradiated with 44 Mc waves[96] the effects appeared to be of a stimulating nature which was proportional to the duration of the radiation. There appeared to be no abiotic effect.

Similar studies on diphtheria bacilli with 52 cm wave-length radiations on suspensions in distilled water produced no effect. Irradiations of cultures in cystine-blood agar with 3.5 m and 15 m waves showed that heat was the only factor which influenced the bacteria.[52]

Investigations of the development of trichinella spiralis in the white rat[59] led the investigators to conclude that the short wave radiation had a marked retarding effect upon the development of the organism.

These and other studies[43] have led some investigators to suggest the possibilities of the use of high frequency radiation for accelerating some life processes such as in yeast manufacture and also its use as a germicidal agent.

Some investigations of the effect of high frequency radiations on paramecia have been done primarily to prove or disprove the ideas of any athermic effects of the radiation.[66 45] Both groups found no effect other than the heating effect which was lethal regardless of the medium, provided that the temperature reached certain levels. The frequencies used varied from 10 to 75 Mc.

[illegible]

CHAPTER III

THE ACTION OF HERTZIAN WAVES ON MAMMALIAN TISSUES

Temperature Effects

Following the observation by d'Arsonval[33] in 1893 that as the frequency was increased a point was reached where stimulation no longer occurred but a sensation of warmth and prickling of the skin was noted, a considerable amount of investigation of high frequency currents has been done. The majority of it has involved the changes in temperature produced by these currents.

1. Skin and subcutaneous tissues - In 1935 Pratt and Sheard[112] concluded that "the relationship of the heat produced in deep lying tissues to the heat produced in superficial tissues is dependent on the distance at which the condenser plates are placed with respect to the locations of the tissues". They felt that if considerable air space separated the plates from the skin, the deep tissues were heated more than the superficial tissues, and if the air space was small the reverse was true. Some of the work of Schliephake[124] seemed to bear this out. The work of Pratt and Sheard was done with 27.5 Mc currents of an electric field. The following year Coulter and Carter[27] reported a series of experiments in which

living human muscle and fat were tested in both the electric field and the electromagnetic field and of wavelengths of 6, 12, 12 and 24 meters (50, 25, 16.6, and 12.5 Mc). They found no significant differences in heating between these different frequencies.

With the advent of microwave technics (2450 Mc) a considerable amount of interest in this field was awakened and more exacting technics were employed. One of the first reports was made by Krusen et al[79] in which he made the following observations: "With our technic of using 75 ma. (65 watt output) plate current and the director at 5 cm distance for 20 minutes, the rise in cutaneous temperature was usually between 3°C and 5°C, an average of 3.5°C to 4°C. Although in some experiments the rise in temperature of muscles was greater than that of the skin, in others, the relationship was reversed. On the average we could not determine any significant difference in the temperature rises of skin, subcutaneous tissue and muscle to 2 cm depth. However, it should be noted that the control temperatures of the deeper tissues are higher than those of the skin, so that even with similar rises in all tissue layers, the final temperature of the muscle is greater than that of the subcutaneous tissue and the skin. When rises of temperature in four layers of tissue are measured, it is noted that the rise in the deeper layer of muscle is usually somewhat less than in the more superficial layer."

In experiments on the thigh of dogs exposed to microwave radiations Osborne and Frederick (1948)[106] reported that, following exposure the maximum temperatures were found at the subcutaneous levels and a decrease in temperature with increasing depth was noted. The average temperature at 2 inch depth was 40.1°C. In similar studies on the human thigh they found that the average temperature reached was essentially the same. In the latter series a minimum of crythema was noted and one blister (24 experiments). Horvath et al (1948)[61] concluded that "the magnitude and depth of heating can be modified by varying directors and the power output of the generator." The maximum temperatures they observed, following a 15 minute exposure to the radiations of a microwave generator with a power output of 50 watts and a 6 inch director were 36.4°C at the surface, 44°C subcutaneously and 40°C in the muscle.

In a comparative study of the temperatures produced by microwave and short wave diathermy Rae et al (1949)[115] concluded that although there was considerable variation in the temperatures produced by the different short wave generators, the difference between the temperatures produced by microwave director A and by some short wave generators were not significant. With this same microwave director they found that higher temperatures were obtained after 20 minutes than after 30 minutes of exposure. They also noted that immediately after short wave diathermy, the temperatures of the deep muscle (3 cm) rose for a variable number of minutes. They also concluded that the "ratio of the increase of temperature in the deep muscles to that in subcutaneous tissues was higher after microwave than after short wave diathermy." In a similar study done by Murphy et al[101] (1950) in which the heating efficiency of 1600 cm, 75 cm, 12.25 cm, 8.5 cm, 3 cm and infra-red rays in both living and dead animal tissues was investigated, it was concluded that: "(1) the increment of temperature change was greater during the first ten minute period of irradiation of living tissue than during the second ten minute period; (2) high frequency irradiation caused a greater increase in temperature in dead tissue than in living tissue during comparable heating periods; (3) the ratios between the temperature increase at 3 cm depth to that at the 1.5 cm depth is greater for the longer wavelengths than for the shorter; and, (4) the ratio of the temperature increase at the subcutaneous level to the temperature increase at 1.5 cm level is greater for the shorter wavelengths than for the longer wavelengths; (5) a greater temperature elevation occurred in the superficial tissues than in the deeper tissues when irradiation was carried out with high frequency electromagnetic waves."

Temperature changes in living tissues exposed to radiation of this nature are quite obviously the result not only of the absorption of energy and the transformation of this energy to that of heat but also the dissipation of that heat principally by the blood stream from the area of absorption. One might therefore conjecture that the blood-flow would increase under conditions of high absorption in order to maintain a normal temperature locally. In order to study these effects on peripheral circulation Gersten et al (1949)[45] made 254 observations on 50 normal human subjects following the exposure to microwave radiations. They concluded that: "(1) Significant increases of blood flow and of tissue temperature in the exposed extremity resulted with both outputs - 60 and 80 watts - and all durations - one to thirty minutes, (2) the greatest amount of energy absorbed was, on the average, in the muscle, (3) after absorption of energy reached a certain point, the increase of blood flow was sufficient to remove heat at a greater rate than it was accumulating, resulting in a fall of tissue temperature from the peak reached at 20 minutes of exposure. The greater the increase of circulation, the greater the decrease of the temperature of exposed tissues from the maximal values reached. After 30 minutes of exposure significantly greater increases of blood flow resulted from 80 watt exposure than from 60 watts, and (4) the curve relating increase of blood flow to duration of exposure at 80 watts is "S" shaped and indicates an early phase of acceleration of the increase of blood flow, followed by a phase of retardation."

The effects of an impaired circulation during periods of exposure to microwave was studied by Worden et al[138] (1948) in which they used a generator with a 30 watt output. Dogs were used in this study; ischemic tissues were produced by ligation of the femoral artery and exposing the thigh. It was found that "temperature rises in ischemic tissues were slightly higher than in the normal but not considered significant after 5 or 10 minute exposures. After 15 or 20 minute exposures the increase in temperature in the ischemic tissues was significant — gross evidence of burning was noted in ten of eleven subjects."

The effects of radiation with "short wave" (frequency not given) on transplantable tumors both in vivo and in vitro was investigated and reported in 1940 by Johnson.[65] For these experiments he used the Jensen rat sarcoma and the Walker rat carcinoma. In order to produce a 50% regression of the former, exposures of 25 minutes with temperatures in the tumor of 47°C were necessary. With temperatures of 45°C and 43.5°C, 1 and 3 hours of exposure were necessary. In a similar series with the Walker rat carcinoma the temperature - time ratios were: 47°C : 45 min; 45°C : 1-1/2 hrs; 43.5°C : 6 hrs. No lethal effects were observed if the temperatures did not exceed 41.5°C.

The effects of implanted metal on tissue hyperthermia have been investigated. Etter (1947)[38] using frequencies of the order of 16 and 44 Mc found no temperature differences between control and metal implanted sites. On the other hand, Feucht et al[41] (1949) reported a greater increase in temperature in tissue containing the implants. This increase was of sufficient magnitude to cause gross damage in contiguous tissue and between the metal plate and the surface. They concluded that "with careful use, it seems likely that during microwave (2450 Mc) irradiation there is little danger of burning a patient who either had metal implanted or metal inbedded in tissue. In most instances the metal is not as large or as close to the surface as described in this report."

2. <u>Bone and articular tissue</u> - Since the advent of high frequency currents in therapy considerable interest has been directed to the question of whether high temperatures could be produced in deep structures without correspondingly high temperatures in the superficial tissues. Using 27.5 Mc currents Sheard and Pratt (1934-1935)[113] reported higher temperatures in intra-articular tissues than in muscle. They also found that in dead animals the bone is heated much more markedly than muscle. Following exposures to the radiation of a spark gap generator (about 1 Mc) for 35 minutes daily for one to four weeks, Weinberg (1934)[131] reported increased temperatures in the bone and also acceleration of new bone formation. He attributed this to an increase in local circulation due to production of local heat.

The effects of microwave radiation on bone and bone marrow was investigated by Engel et al (1950)[36]. For these experiments dogs were irradiated both over submuscular bone and over subcutaneous bone and the temperature compared, with the following results:

	Submuscular (tibialis anterior)	Subcutaneous (gastrocnemius)
Subcutaneous	4.3°C	4.1°C
Muscular	4.6°C	4.3°C
Tibial cortex	3.8°C	5.0°C
Tibial marrow	3.0°C	3.4°C
Rectal temp increase	0.3°C	0.2°C

These are average temperature increases following a thirty minute exposure.

3. <u>The eye and surrounding structures</u> - In 1939 Puntenney and Osborne[114] reported a study of the temperature changes and changes in the caliber of retinal blood vessels following the exposure of anesthetized dogs to a six meter (44 Mc) ultratherm. The duration of these exposures were ten and twenty minutes, using Schliephake glass electrodes at two inches target distance. They found that the temperature increase immediately after exposure was much higher in the subconjunctival tissues and the vitreous than in the orbit itself. No changes in sizes of retinal vessels were detected and no abnormalities were noted on pathological examination of the eyes subsequently. Later in 1948 Osborne and Frederick[106] reported a series of acute experiments on dogs using a microwave generator. The average temperature of the vitreous body following exposure was 105.8°F (40.9°C). One animal receiving six treatments in three weeks showed no pathological changes.

In six experiments exposing the frontal sinus of dogs the average temperature following exposure was 105°F. Richardson et al (1948)[117] reported temperatures of 55.1°C at the posterior pole of the lens and 49.4°C at the cornea was observed following exposure to microwaves (rabbits).

4. Nervous system - Intraspinal temperatures were increased an average of 2.6°F as compared to 0.7°F and 1.1°F, oral and rectal temperatures, respectively, following exposure to 50 Mc currents for twenty minutes.[12]

5. Intrathoracic structures - In an extensive study of the factors involved in heating the lung with high frequency currents Binger and Christie (1927)[13, 14] found that a 1.2 Mc spark-gap generator was able to raise the temperature of the lung about 0.3 to 0.4°C above that of the rectal temperature, which is approximately the reverse relationships between these two temperatures in the unexposed dog. However, immediately after the death of the dog and with continued irradiation the temperature rises abruptly in the deep tissues. If the access of air to one lung is prevented there is little if any change in the rate of heating of that lung. On the other hand, if both the venous return and the arterial supply to an otherwise normal lung is occluded the local rise in temperature in

the lung is equivalent to that in the other lung after death. If only the arterial supply is occluded there results a sudden rise in temperature in this lung but subsequent heating is at the original rate. When dogs were innoculated with B. friedlanderi, Type B and Pneumococcus, Type I so as to produce a lobar pneumonia in only one lung as shown by X-ray and then irradiated the affected - consolidated - lobe showed a more rapid rate of heating than the normal lobe, the final increase amounting to slightly more than 1° C. The local heating was of the same order of magnitude as that found when only the arterial supply was occluded. This might be expected in view of the pathological finding of the presence of intra-alveolar capillaries.

6. Cardiovascular system - The effect of the application of high frequency currents to the thorax in respect to the temperature of the circulating blood was a subject of study by Binger[14] and Christie (1927) in which they found that the temperature of the blood in the left side of the heart exceeded that of the right side by about 0.05°C to 0.2°C which is the reverse relationship found prior to exposure. They concluded that "this indicates that the lungs are being heated but that the blood passing

through the pulmonary vessels is removing the heat at approximately the rate of production."

The work of Heinle and Phelps[52-54] (1933) done on perfused cats' hearts showed no evidence that the elasticity of the aortic rings was affected by radio waves. They did find an immediate elevation of heart temperature which was accompanied by increased rate and amplitude of ventricular beats, but which disappeared when the rise in temperature was compensated by reducing the temperature of the perfusion fluid.

7. Generalized hyperthermia - In 1930 Carpenter and Page[19] described a method by which a patient could be irradiated in order to produce and maintain for several hours artifical fevers of from 104°F to 105°F by exposing him in a non-heat-conducting box in which only his head was left uncovered. They found that the frequency of 10 Mc was more efficient than that of 55, 22, or 18 Mc. The method described was that of an electric field between condenser plates (28 x 18 inches).

Physiological Effects

1. Blood flow - In 1931 Pflomm[1] claimed to have demonstrated a dilation of capillaries after irradiation. He observed that the dilation persisted for about two weeks and was not affected by the administration of epinephrin.

Although this evidence was presented to prove a specific effect of high frequency current other than that of heat, Weixz[133] et al in 1938 reported a series of experiments on the webs of frog tongues which were irradiated with 60 Mc currents for six to twenty minutes. They concluded that the same dilation of the vessels took place during irradiation as that which occurred when the tongue was heated with Ringer's solution at the same rate and to the same degree. When the tongue was cooled during irradiation no dilation occurred.

Peripheral vasodilation in human extremities was demonstrated following application of short wave diathermy (frequency not given) to the lumbosacral area by Bennett[8] et al (1941). This vascular response was predicated on the change in surface temperatures of the feet as recorded by thermocouples. In comparing the results with that produced by tub heating and infra-red they found that following the latter two modes of therapy, application of short wave diathermy resulted in an additional rise of 3.1°C. Mart and Miller[89] (1945) could demonstrate no significant increase in coronary flow following irradiation over the region of the heart in dogs.

Although there are numerous apparently conflicting reports concerning the effects of various frequencies on blood flow, there seems to be general agreement that microwaves (2450 Mc) quite uniformly produce an increased flow. There can be little doubt that where the absorption of sufficient energy has occurred the flow of blood from the area is increased. The reasons for the discrepancies, which are apparent, are that under the conditions of the experiment the absorption of energy has not reached the critical level required to produce an increased flow. This is partially shown by the low grade deep tissue temperatures achieved. It does appear that under the current methods of application of microwaves as compared to the various short wave methods, the former is more efficient.[81,136,127,69,42,116]

Krusen et al (1947)[79] found that "accompanying the rise in temperature produced in the extremity which was exposed to microwaves, there was a consistent increase in return of venous blood. Furthermore, with the gradual return of the temperature of the tissues toward control level, there was also a gradual return of the flow of venous blood toward the initial level. In summary, it can be stated that the local heat produced in the tissues by exposure to microwaves brings about an increase of venous return and a vasodilation through local reflex mechanisms and direct metabolic effects. Whenever a general rise in temperature of the body occurs, the vasodilation becomes generalized through action of central hypothalamic mechanisms. The heart rate may be increased by speeding up the rate of generation and propagation of impulses, through the sino-auricular node."

The effect of short wave and microwave application to the back and its effect on renal blood flow led Kottke et al[75] (1949) to conclude that such application causes a decrease in the deep blood flow (renal). They compared the following frequencies - 2450 Mc, 27.3 Mc and 15 Mc. The renal circulation was estimated with the use of the clearance of sodium para-aminohyppurate at blood levels of 2 to 5 mg% to estimate renal blood flow and clearance of sodium thiosulfate at blood levels of 10 to 20 mg% to estimate glomorular filtration. This work was done on normal healthy human subjects so temperature changes in the kidney parenchyma were obviously not recorded. It seems entirely possible that the absorption of sufficient energy did not occur in the renal tissue but rather in the more superficial tissues thereby actually tending to divert the major blood pool to the muscles and other more superficial tissues rather than to kidneys in order to dissipate the heat in tissues where such dissipation was most greatly needed.

2. Blood and its constituents - Following the advent and use of high frequency induction of hyperpyrexia numerous studies have been made of the blood and its constituents. One of the earliest studies was made by Nasset and Warren[102] reported in 1929-1930 in which a frequency of 1.5 Mc was used on anesthetized dogs. They found an initial hyperglycemia with gradual depletion during exposure with an end result of a marked hypoglycemia (30 to 50 mg%); the non-protein-nitrogen increased to about 200% of normal; the CO_2 content of whole blood and of plasma invariably dropped to a low level (35%). The blood chlorides failed to exhibit any change. In these experiments the body temperature rose from 5° to 7°C above normal figures. Mortimer[100] (1931) reported similar changes in dogs subjected to sublethal doses. Knudson and Schaible[72] (1931) found that the NPN generally increased; Urea nitroten, creatinine and amino-acid nitrogen also increased. They felt these increases were due to increased metabolism resulting from the rise in temperature of the body and to the oliguria which result ed. These experiments were done with generators of 9 to 12 Mc currents. Investigations reported by Giles[47] (1935) from cases of articial fever in human therapy revealed an increase of NPN to about 11% returning to normal in a few days; also an increase or urea

N of 13-19% which returned to normal soon after elimination of the fever; blood sugar increased up to 20%; there was no increase in uric acid and creatinin, but a temporary decrease in chlorides.

The cellular elements of the peripheral blood show significant changes during this type of hyperpyrexia. Knudson and Schiable[72] found an increase in both red and white blood cells and in many instances there was a marked increase in immature red cells, suggesting a stimulation of the hematopoietic tissues. Giles[47] found a fluctuation of leucocytes of from 10,000 to 50,000 p. ccm. throughout therapy (human) with the percentage of neutrophils increasing to the same magnitude as the decrease in lymphocytes. The Arnett-Shilling index showed a shift to the left which was considered evidence of hematopoietic stimulation. This leucocytic response was in proportion to the degree of temperature rise.

The studies of Knudson and Schaible on dogs showed a decrease in blood volume up to 25%, along with an increase in cell volume and concentration of hemoglobin. The work of Giles[47] demonstrated an early increase in blood volume which he suggested was due to the absorption of fluids from the intestinal tract muscle, and other tissues at the time of the initial temperature rise. In a series reported by Osborne[107] (1941) of patients undergoing fever therapy and with temperatures maintained at 104°F, it was found that it patients were given ample quantities of fluid containing sodium chloride there were no significant changes in the specific gravity of the blood. He concluded that "apparently, increased blood density is not the mechanism responsible for the changes occurring in the blood cell count when adequate fluids are administered during the course of treatment."

The circulatory reactions during hyperpyrexia were reported in 1932 by Wiggers and Orias[135] in a series of experiments on anesthetized dogs which were exposed to radiations of 10 Mc. They concluded that "qualitative and quantitative studies of the circulatory reactions reveal certain differences in hyperthermias produced by high external temperatures and by radiothermy. In the hyperyrexia due to the former, blood pressures tend to decline with temperatures above 41°C. The pulse pressures become smaller, rise more gradually to a peak and are devoid of all secondary vibrations. In short, they display features which suggest that diastolic discharge is reduced and the force of ventricular contraction is decreased. During radiothermia, on the other hand, systolic and diastolic pressures increase tremendously after heart temperatures exceed 41°C. The pulse pressure increases greatly in amplitude, rises sharply to a peak and contains many after-vibrations. All of these features suggest that the force and vigor of ventricular contraction are improved until the crisis is reached. --- When radiothermy is continued long enough, death occurs as in other forms of hyperthermia, i.e. through primary failure of the respiratory center which is followed by circulatory failure due to asphyxia."

3. Respiratory Tract - Nasset and co-workers[103] (1931) have shown in anesthetized dogs that the respiratory metabolism as determined by the Benedict Universal apparatus was increased from 27 to 172%. The respiratory rate in some cases increased twenty-five fold (temperature rise 3.6°C to 8.5°C) with a reduction in the carboon dioxide content of the expired air to 0.5%. There was apparently no difference in the response elicited by 1 Mc currents as compared to that of 10 Mc. They felt that this evidence did not suggest any specific effect of the high frequency current on oxygen consumption of the animals which is in line with the work of Fenn and Latchford[40] who measured the oxygen consumption of the sartorius muscle in frogs during exposure to currents of 10 Mc and 100 Mc. and concluded that the increased oxygen consumption could be attributed entirely to the heating effect of the current.

4. Genitro-urinary tract - In repeated exposures of young rats to frequencies of 9 to 12 Mc for one-half to one hour daily, Knudson and Schaible (1931)[71] found no loss in breeding power. The body temperatures of these rates was raised to 40.5°C. Follis (1943)[44] using guinea pigs and a generator emitting waves in the "S" band (3000 Mc) found no loss in reproductive activity after three-hour exposures daily for fifty-one to fifty-three days. No significant temperature changes were noted in this series. Oliguria and anuria were found to be almost invariable sequelaw to hyperthermias of 42°C or higher in dogs, according to Karr and Nasset (1934)[67], who suggested that "dehydration and damage to the renal parenchyma are important factors in the loss of kidney function." These experiments utilized radiations of about 1 Mc in frequency.

5. Gastro-intestinal tract - Under the influence of 47 Mc currents McLoughlin et al (1941)[94] found in experiments of the exteriorized loops of intestines in dogs that the effects were similar to those produced by conventional forms of heat i.e. amplitude, tonus of contractions, strength of contractions, but a slight increase in the rate of rhythmic contractions.

The action of 50 Mc waves on the flow of bile in rabbins and dogs was studied by Leskovar (1940)[82], who demonstrated a mild chloresis whose magnitude was not as great as that of mineral water containing considerable magnesium.

6. Thoracic Duct - Herrick and Bellman[58] (1948) using rats found that when the body temperature was elevated more than $2^{o}C$ in fifteen minutes, the flow of lymph was reduced for fifteen to thirty minutes subsequently before returning to normal. This phenomenon was similar whether produced by high environmental temperature and humidity or by microwave irradiation.

7. Central Nervous System -- Looney and Borkovic[87] (42-43) found no increase in brain metabolism in studies made on cerebral blood in twelve patients receiving diathermy treatment. This conclusion was predicated on determinations of cerebral blood sugar, lactic acid and pH during hyperthermia.

Pathological Effects

In 1926 Schereschewsky[123] following exposure of small laboratory animals to varying frequencies reported that "this effect (lethality) is most marked in a certain band of frequencies extending from 66 to 18.3 Mc, the effect diminishing in one direction from a band extending from 66 to 135 Mc and in the other from 18.3 to 9 Mc."

1. <u>Cardio-Respiratory System</u> - Hosmer[62] (1928) reported that "in rats killed after sublethal treatments (apparently 60 Mc) the only evidence of tissue damage yet observed has been in the outer layers of the muscle cells of the heart immediately adjacent to the pericardial cavity and at the tips of the liver lobes. Such treatments have been shown to raise the temperature of the region exposed, in this case the lower thorax to 115°F in three minutes without affecting the rectal temperature."

Baldwin and Nelson[6] (1929) using albino rats exposed to 5 or 6 Mc currents for four to thirty minues demonstrated an incipient coagulation necrosis of the periphery of the lungs and heart. This occurred quite constantly if rectal temperatures were maintained for ten to thirty minutes at 40° to 42°C. In a study of seventeen cases of death following therapeutic hyperpyrexia which were reviewed by Gore[48] (1949) it was found that the heart exhibited necrosis of cells and other degenerative changes microscopically.

2. <u>Gastro-Intestinal Tract</u> -- The gastro-intestinal tract was the most frequent site of pathological change. Baldwin and Nelson[6] found the "stomach and proximal duodenum normal but beginning with ampulla of Vater the mucosa was degenerated and exfoliating. This process involved

the submucosa and fundus of the intestinal glands." Of another series Baldwin and Dondale[5] described the small intestinal lesions as a "coagulation necrosis first in epithelial lining cells but involving stroma eventually; exfoliation of epithelial cells was the rule while vascular dilation, leucocytosis, hemorrhages into the villi, submucosa and muscularis were characteristic. The regenerative process began soon after the last raying--completed by 5th to 7th day, but delayed in two instances for two months." These findings were largely confirmed by Jacobson and Hosoi[64] (1931) in dogs, rats, and guinea pigs.

The liver sinusoids were dilated and filled with blood cells while leucocytes with fragmented and pyknotic nuclei were conspicuous within the blood vessels and among the liver cells[5]. Jacoben and Hosoi also noted congestion, peripheral hyperemia, cloudy swelling, fatty degeneration and focal hemorrhages. This also was confirmed by Gore[48] in the seventeen cases autopsied following fatal hyperpyrexia.

3. Genito-Urinary Tract -- The kidneys in Baldwin and Nelson[6] series demonstrated extravasations of blood into the cortex and medulla, the glomeruli were dilated and the capillaries filled with clotted blood. The cells lining the convoluted tubules and ascending loop of Henle were

degenerated. Using currents of about 50 Mc on guinea pigs Kling[70] found that "the most constant changes found were in the testicles. These consisted of the destruction of mature spermatogenic cells and the presence of giant cells. There was some hyperplasia of the Sertoli cells. This was independent of the degree of heating and the manner of application." Imig et al[63] (1948) reported a study in which 12 cm (2450 Mc) waves were compared with infra-red waves as to their effect on the testes of adult albino rats. Although they could not differentiate the histological picture in these two modalities, the damage seemed to occur at lower temperatures (35^oC) in the central portion of the testicle in the case of microwaves as compared to 40^oC when infra-red was used. The typical histological picture in this series was described as "- - - an area of degeneration along the side of the testis nearest to the source of irradiation. Continuing from this area of degeneration to the opposite side of the testis, all radiations can be found, absence of germ cell nuclear material, the cytoplasm appearing much more refractile than normal. The tubules show sloughing of degenerating germinal elements into the lumen, multinuclear masses termed "giant cells" which apparently consist of fused spermatid nuclei and usually absence of spermatozoa. The Sertoli and interstitial cells apparently remain intact. The duration of these exposures was five and ten minutes. In the experiments of Baldwin and Nelson[6] the sex organs were reported as normal. In a series reported by Follis[44] in which he exposed guinea pigs to repeated doses of "S" band radar (3000 Mc) no pathological changes were noted.

4. Nervous System -- By exposing rabbits to microwaves at almost contact distance from the shaved scalp for a period of three minutes Oldendorf[105] (1949) produced focal cerebral lesions which he described as a "grossly yellow-green coagulation lesion 0.7 x 1 cm on superior surface of the cerebral hemisphere. Histologically the small lesion appeared sharply circumscribed. It involved the cortical gray matter in its entire width and extended somewhat into the subcortical white matter. The whole lesion contained no intact nerve cells or glia and was delimited by a wall of intensely proliferating glial cells." Death occurred in one rabbit so described, on the 15th day following exposure.

5. The Eye - The production of lenticular opacities has been reported in both rabbits and dogs as a result of exposure to microwaves. Richardson et al[117] (1948) found that a sixteen minute exposure of rabbits' eyes to 12.25 cm

microwaves (100 watts power output) at a target distance of 5 cm would result in cataractous lenticular opacities after a delay of three to nine days. Under these conditions the average temperature of the vitreous at the posterior pole of the lens was found to be 55.1°C and that of the cornea was 49.4°C. When the exposures were of smaller magnitude and repeated the delay in production of cataracts was two to forty-two days; however, if the irradiation was of seventeen to twenty minutes in duration the cataracts developed immediately.[31] Daily et al (1948) in a study on anesthetized dogs found that when eyes of dogs were exposed for thirty minutes at a target distance of three inches using about 75% output (about 90 watts) from a corner director that the temperature rise in the orbit was 1.9°C, in the vitreous 3.2°C and in the aqueous, 2.8°C exactly one minute after the microwave generator was turned off. In another series under the same experimental conditions there was no clinically observed pathology when the eight dogs were exposed six to ten times. However, one dog developed an anterior certical cataract within six days of the last of eight exposures each of thirty minutes duration at a two inch target distance. Seven similar exposures to the eye of another dog using 98% output at one inch distance produced an anterior cortical cataract within twenty-four hours of the last exposure. Over a period of nine weeks these anterior cataracts increased in size and density, then regressed and posterior certial cataracts developed. In another dog exposed thirty minutes, one time only, with a 75% generator output at a target distance of two inches corneal clouding and a partial iridoplegia was produced in twenty-four hours. This eye on microscopic examination showed a round cell infiltration or the corneal stroma. Similar clinical and histological changes were produced in the eye of another dog within twenty-four hours after two thirty-minute exposures and in addition, vitreous opacities, reddening of the optic disc, whitening and elevation of the retina in the region of the disc were observed ophthalmoscopically. Microscopic examination revealed RBCs, leucocytes, and fibrinous exudate in the anterior chamber with hemorrhage into the iris and ciliary processes. Necrosis of the iris stroma and disorganization of the pigment layer of the iris and subchoroidal exudate and cystic degeneration of the retina were also observed."

6. <u>Skeletal System</u> -- The effect of both short wave and microwave diathermy on bone growth was reported by Wise et al[137] (1949). These studies were done on albino

rats in which the region of the knee joint was given a single exposure (shortwave - 8 meter wavelength; microwave - 11 cm wavelength). The animals were killed at varying intervals for study of changes in bone length, soft-tissue change, x-ray and microscopic changes. They concluded that "when moderate soft-tissue injury was present immediately after exposure to either short wave or microwave radiation, the subsequent effect on bone growth -- shortening deformity, partial or complete epiphyseal destruction, etc, did not always parallel the extent of soft tissue injury. An unusual sequella to microwave burn was characterized by extensive bone absorption and resulting flail extremity (entire femur)." They also reported two clinical cases of extensive disturbances in bone growth which followed diathermy burns in children.

Lidman and Cohn (1945)[84] in a study of 124 radar instructors, and technicians who had prolonged exposure to emanations from both shielded and unshielded radar equipment was unable to uncover any evidence that might "indicate stimulation or depression of the crythropoietic and leucopoietic systems."

PART II

CHAPTER I

EXPERIMENTAL STUDIES

Purpose

Investigations concerning the biological effects of radiations of the Hertzian portion of the electromagnetic spectrum have limited themselves primarily to that portion below 100 Mc, and since the advent of the magnetron tube to the region of the "S" band of radar (2450 Mc), which has recently been assigned to medical therapeutic equipment such as the Microtherm. Although there are a few exceptions to this, the volume of work has been slight. Certain of the investigations involving the lower frequencies have given results which, if interpolated, would lead one to suppose that a frequency of the order of 300 Mc would be the optimum for heating solutions or materials which are isotonic with blood. Frequencies of this order of magnitude are also used at present in some commercial applications such as radar and television. Because of the physiologic implications of this type of use, further knowledge concerning the effects of these frequencies was thought to be highly desirable.

It was therefore proposed to expose experimental animals to radiations of the order of magnitude of 350 Mc so as to determine their increase in body temperature and secondly, to discover the nature of any pathological changes which might occur. Furthermore, it was considered expedient to conduct these exposures in a wave-guide in order to measure with some degree of accuracy the actual energy absorption by each individual or each pair of exposed animals. This method also provided a convenient method of tuning the transmitter so as to repeat as nearly as possible the experimental conditions from one experiment to the next.

Experimental Equipment

1. Power Source - Power was obtained from a standard commercial power line (220 volt, 60 cycle) fed into a generator-alternator mechanism in order to obtain the following power for operation of the transmitter:

a. d-c power: 28 volts, 11 amps.

b. a-c power: 1500 volt-amps, 400 cycle.

2. Transmitter - (Radar Set AN/APT-4) - This apparatus consisted of three separate units:

a. Transmitter - T75/APT-4 (USAF) - This set contained the oscillator tube (JANS-J30) which has a possible frequency range of 175 Mc to 400 Mc., the timing and loading mechanisms, and the air and water cooling systems which are necessary for cooling of the oscillator tube.

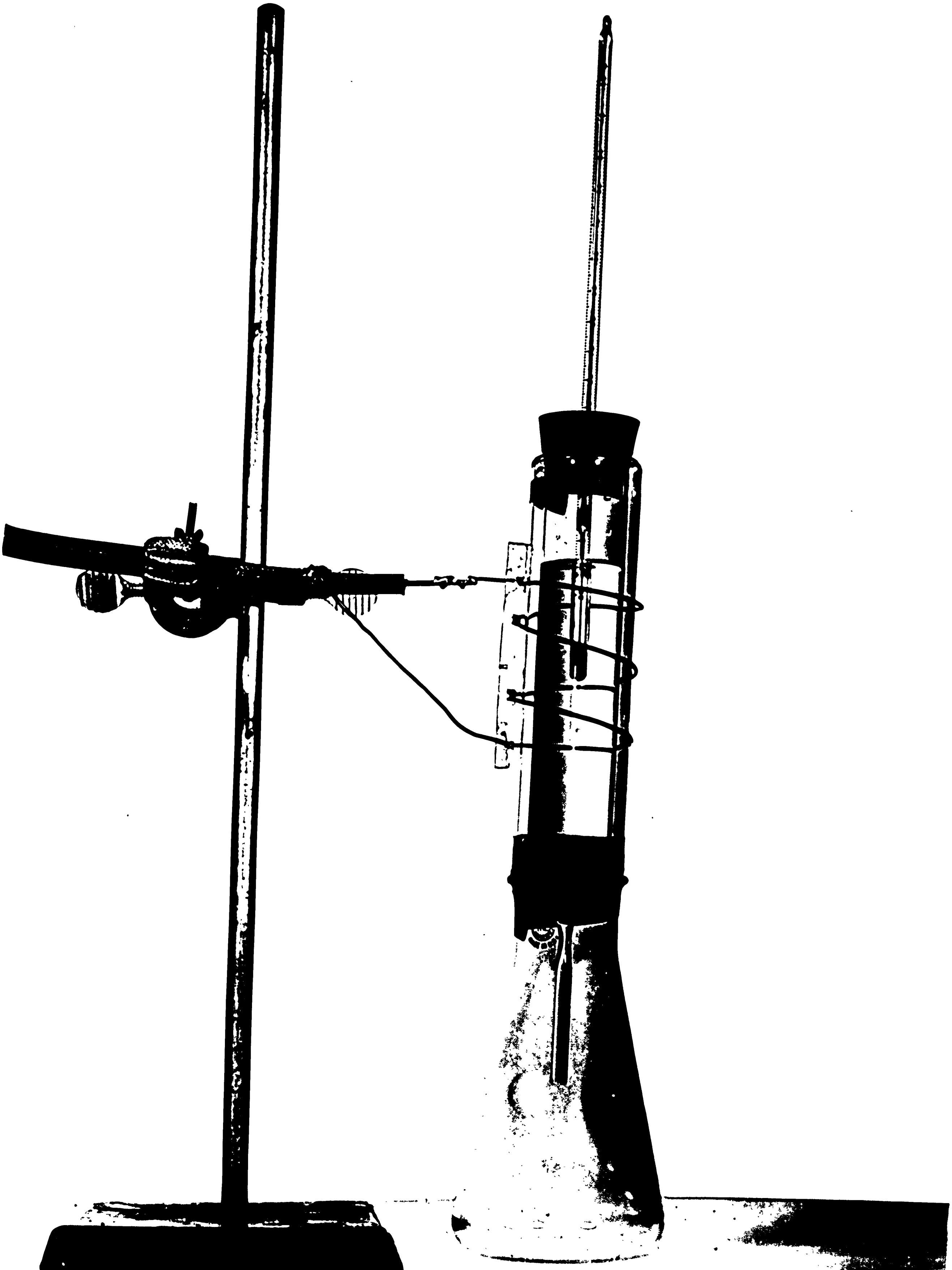
b. Modulator (MC-30/APT-4) - This unit contained most of the power controls for the radar set. The video amplifier was a wide band noise generator (up to 5 Mc band-width) and amplifier. The final tubes are a pair of JAN-813's operated in parallel, which modulate the oscillator tube of the transmitter.

c. Rectifier Power Unit (PP-87/APT-4) - Voltages up to 3000 volts d-c and up to 3500 volts rms a-c were developed in this chassis. Inside the unit were the high voltage rectifier and its associated filter and bleeder circuits. The time delay circuit was also located in this unit.

3. <u>Antenna Assemblies</u>

a. Coil Antenna - This antenna is shown in Figure 1 and consists of a coated copper wire attached to a coaxial cable antenna lead. This antenna was used only in the experiments upon saline solutions.

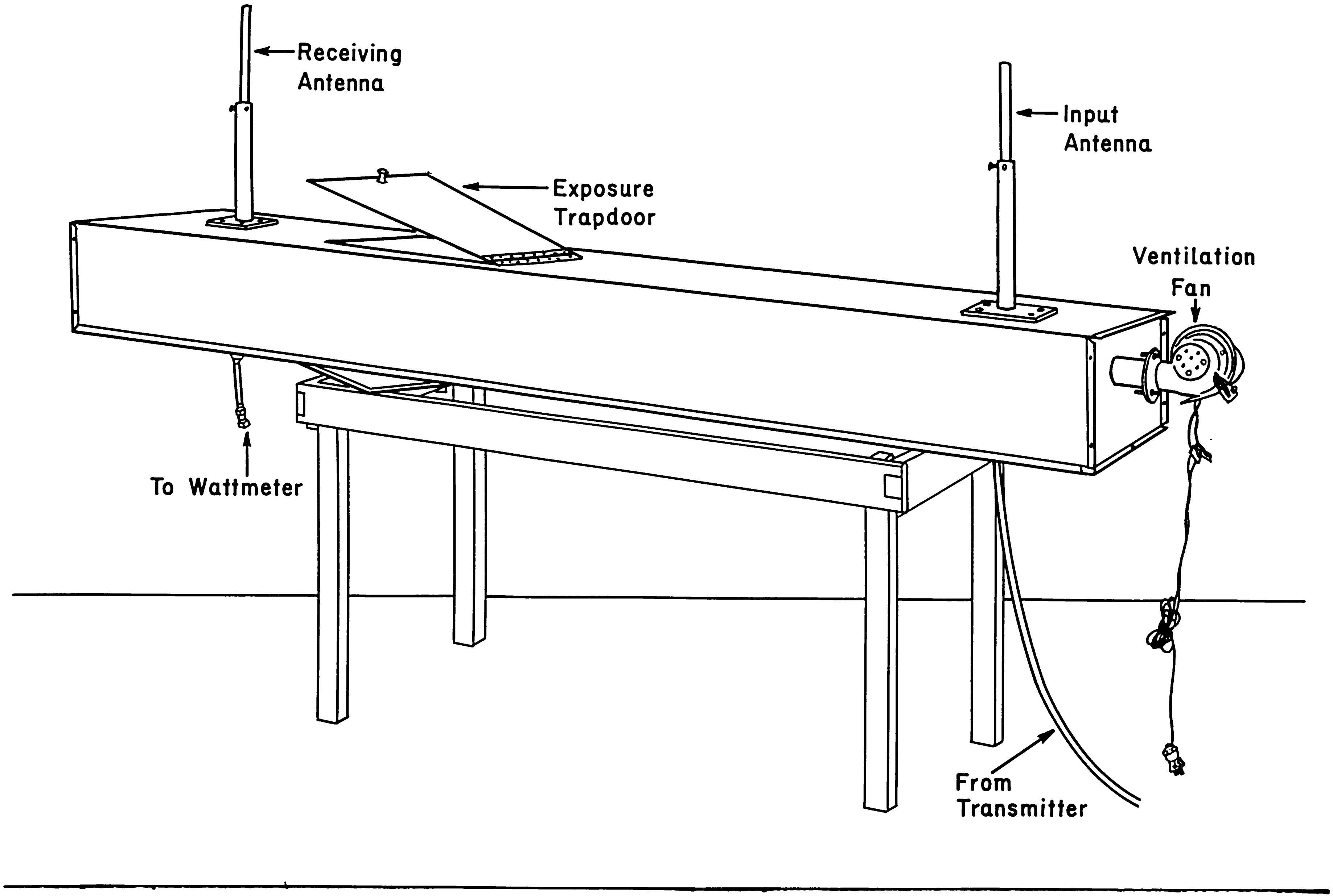
b. Cone Antenna (AS-115/APT) - This assembly consisted of a plated metal cone intended to cover a range of 250 to 770 Mc with Radar Set AN/APT-4. The metal cone was supported on a fiber-glass skirt which housed the lead from the antenna to the connector. This assembly was mounted on the base of an oscillating fan in such a



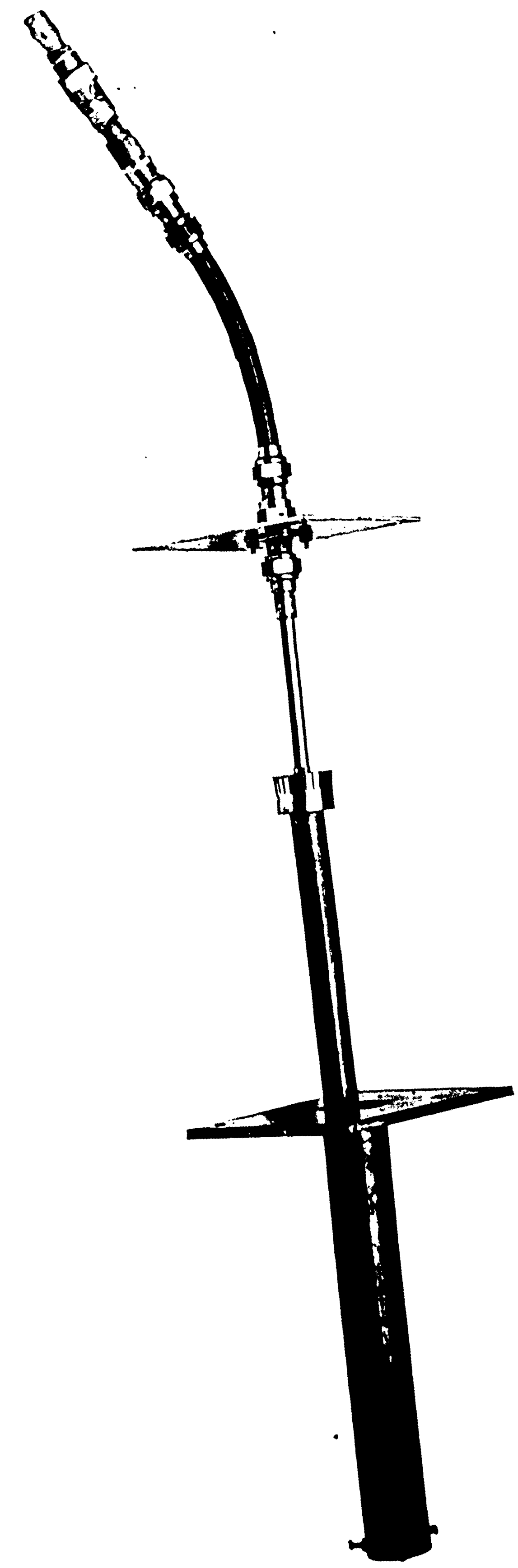
manner that it swung through an arc of about 90°. This antenna was used solely in the series of experiments in the "decompression" chamber.

c. Wave-guide - This assembly consisted of a copper chamber eight feet long, twenty-four inches wide, and ten inches deep. (Figure 2). The transmitting antenna assembly extended vertically through the chamber, ten inches from the end. At the opposite end, the receiving antenna extended vertically in a like manner and was also ten inches from the opposite end. A trap door (19" x 19") was situated twenty-four inches from the receiving end of the guide, the hinged portion of the door being forty-three inches from the end, and on the top of the guide. Rectangular holes were cut in the side of the guide in such positions that they would not interfere with the resonance characteristics of the guide but would provide adequate ventilation to the interior. A small rotoclone was situated in the transmitting end of the guide in order to provide adequate and constant ventilation during the experiments.

The transmitting antenna (Figure 3) was constructed in such a manner that it could be tuned by rotating the center hollow tube which increased or decreased its height as it turned on the threaded central



Receiving Antenna
Exposure Trapdoor
Input Antenna
Ventilation Fan
To Wattmeter
From Transmitter



post. This post was electrically connected to the center wire of the coaxial cable from the transmitter. The outermost hollow tube was grounded to the wave guide itself.

The receiving antenna was constructed in a similar manner except that the center post was not threaded. It in turn was attached to the lossy line of the wattmeter.

4. <u>Exposure Chambers</u>

a. Modified DeWar Flask - An unsilvered DeWar flask was set into the mouth of an Ehrlenmeyer flask without evacuation. The volume of the flask was 180 cc. During the experiments it was surrounded but not touched by the antenna. (Figure <u>1</u>)

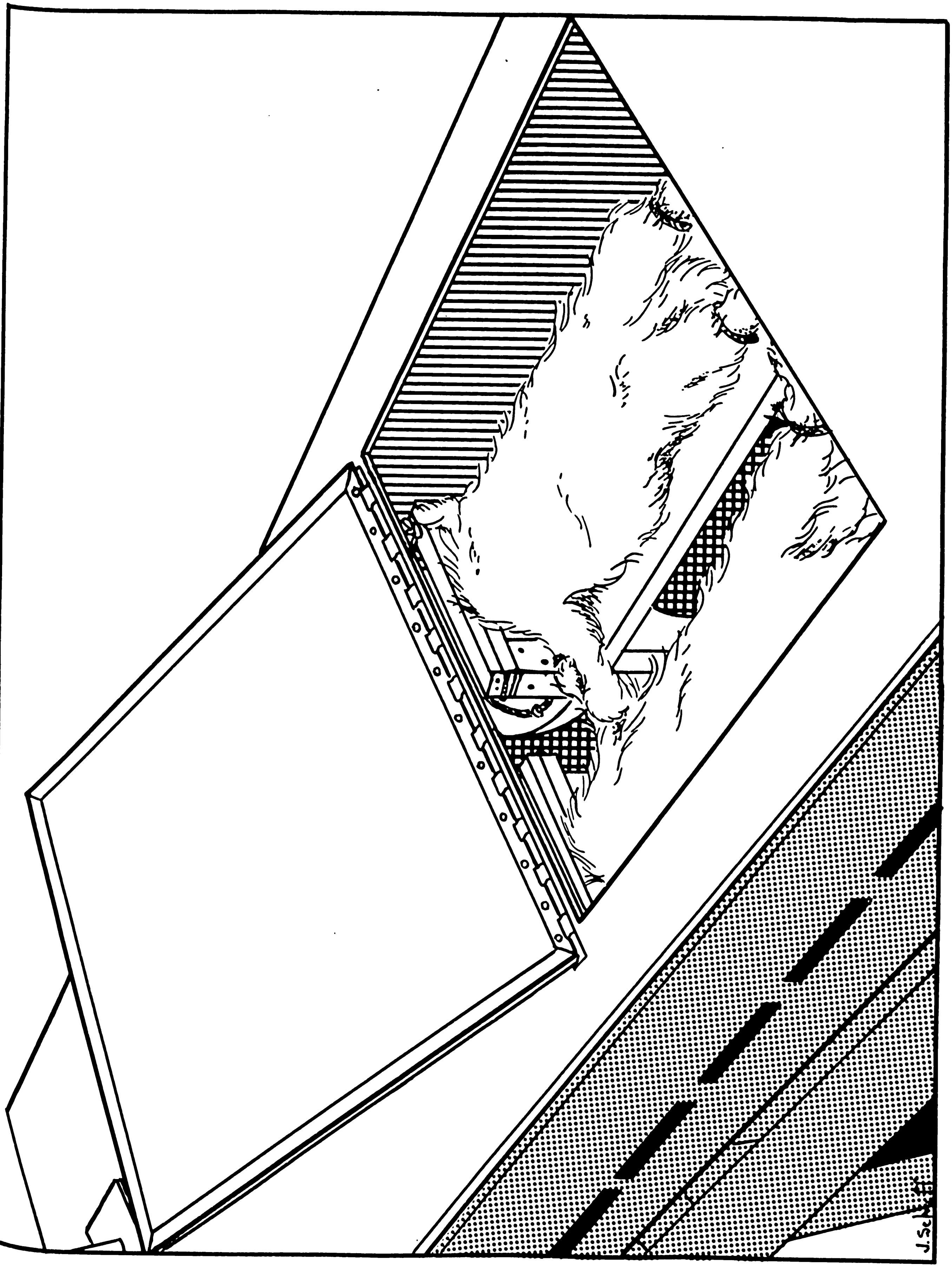
b. "Decompression" Chamber - This steel chamber was a standard decompression chamber used previously for simulated high altitude testing. At no time during these experiments was it used as such but it was employed only for its shielding properties. The cone antenna mounted on the oscillating fan base was attached to the ceiling of the chamber at approximately its midpoint, and pointing downward at an angle of about 45° toward the bench on which the experimental animals were placed. The animals were allowed to move freely about in paper cartons (12" x 12" x 12") which were open at the top. These cartons were used, as they were found to absorb negligible quantities of the radiation used.

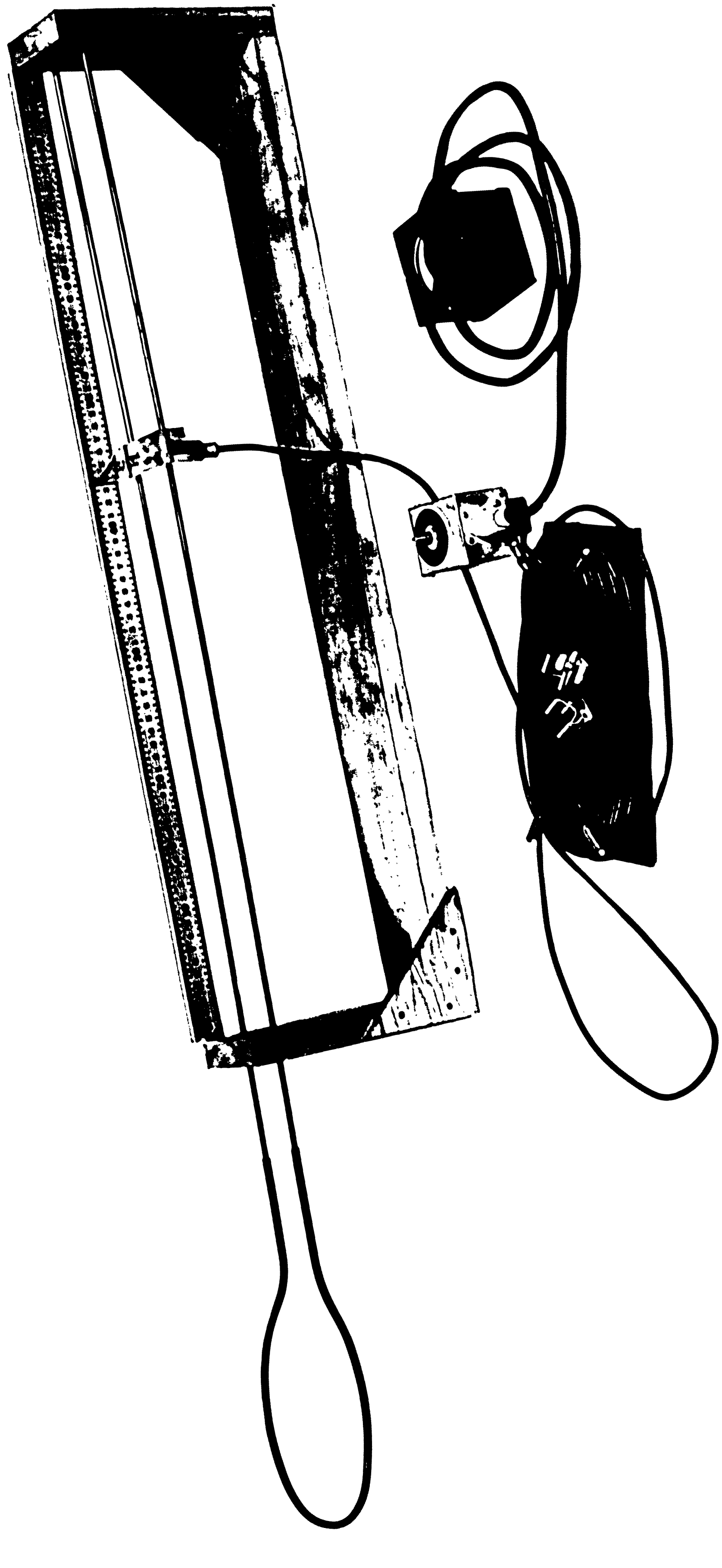
c. Wave-guide Chamber - This chamber was an integral part of the wave-guide and consisted only of the trap door previously described. The animals were placed immediately below the trap door, on animal boards which held the animals in a supine position. These were standard wooden animal boards with no metal parts touching the animal at any point. Most of the exposures were conducted with two animals in the guide during the exposure although a few were performed with only one animal present. (Figure 4).

5. <u>Metering Devices</u>

a. Lecher Wire - This assembly consisted of a metal loop attached to two parallel metal rods with a sliding electrode assembly which was attached to radio frequency meter. This was used to measure the wavelength of the radiation by the standard method of null points.

b. Frequency Meter - (TS-175/U) - Attempts were made to use this equipment but it was found that the very nature of the radiation precluded the use of this meter. It was impossible to approach the "zero beat" because of the random character of the transmitted signal.





c. Radio-Frequency Wattmeter (TS-118/AP) - This equipment measures the r-f power output of inductively coupled raven transmitters operating on frequencies from 20 to 750 Mc with power outputs from 5 to 500 watts. The wattmeter requires no matching section and measures power in terms of deflection on a d-c, 0 - 1 milliameter. The d-c current in the milliameter is produced by a thermocouple, located at the end of the high-loss line ("lossy" line) of the wattmeter, and rises with the power output of the transmitter. Three sizes of thermocouples are provided together with calibration curves. Power required by this wattmeter is 75 to 100 watts at 115 volts, 50-60 cycles a-c.

This assembly was connected to the receiving antenna of the wave-guide by the thermocouple and lossy line. Readings were taken before placing the animals in the guide and after the transmitter and guide were tuned, and again after the animals were placed in position and the guide retuned to maximum power. The difference between the two readings obtained from calibration charts accompanying the instrument was taken as the "absorbed power".

d. Temperature Metering Assembly - This assembly consisted of thermocouple needles constructed after the method of Tuttle and Janney,[129] and a Leeds-Northrup potentiometer. The cold junctions were placed in DeWar flasks containing crushed ice and thereby maintained at a constant temperature of $0^{o}C$. The thermocouples were calibrated against a certified U. S. Bureau of Standards thermometer (Mercury). All experiments which were performed on animals and recorded were obtained in this manner. The temperatures recorded in the series of experiments on saline solutions were obtained with the aid of toluene thermometers.

Procedure and Methods

1. Heating Rate of Saline

The various concentrations of saline were made up accurately with sodium chloride and distilled water. Temperatures of the solutions were taken with a toluene thermometer which was placed in the solution to the proper immersion depth and left in situ during the irradiation. Prior to these experiments it was determined that the radiation had no effect on the thermometer when it was placed in the field of radiation in air. This was confirmed by placing it in distilled water during the experiment.

2. Animal Experiments

a. Species - Rabbits, Flemish Females

b. Laboratory studies -

(1) Weight determinations were made prior to exposure and at certain intervals thereafter.

(2) Temperature studies - Certain of the experiments (SubGroup B) were done with the aid of the thermocouple method. Rectal temperatures were taken prior to exposure and immediately after removal from exposure which rarely exceeded a time lapse of one minute. Temperatures were also obtained during the recovery phase, usually until the temperature returned to the pre-exposure level except in those terminating fatally within a short time after exposure.

Temperatures were also taken subcutaneously and a few with the needle inserted either into the abdominal or the thoracic cavity. These latter temperatures have not been included in this paper as their variations were extreme even though attempts were made to insert the needle in locations previously used.

(3) A physical inspection of each animal was made prior to exposure to determine whether any abnormalities had developed since previous exposures. Ophthalmoscopic examinations were performed at intervals.

c. Pathological Studies - All animals dying during the course of experiments were subjected to careful gross and microscopic post-mortem examinations. Certain selected animals were also killed by intravenous injection of air for post-mortem study. Animals from each exposure group were included in order to determine pathological changes in non-fatal subjects.

d. Control Experiments - Five animals were "exposed" simultaneously in the decompression chamber with the transmitter in operation but with no load on the antenna for a period of two hours. No rise in rectal temperature occurred. Similarly, two animals were placed in the wave-guide for twenty-two minutes and another pair for thirty minutes without showing any apparent effects including hyperthermia.

Character of the Radiation

During normal operation of this transmitter a given carrier wave is produced which is modulated by a noise signal. This noise signal is random in nature and may be varied in bandwidth from a fraction of a megacycle to five megacycles. Such a noise modulated carrier wave is "pulsed". In the series of experiments labeled Subgroups A, B, and C, series 1 these conditions of operation apply. The frequency of the carrier was 346 Mc which was noise modulated-bandwidth of 5 Mc. The loading of the antenna was no problem during the experiments of Subgroups A and B, but was very critical in Subgroup C-series 1. This latter series involved the use of the wave guide, and tuning of the antenna was accomplished by adjusting the length of both the transmitting and the receiving stubs in the wave guide. Such adjustments were cumbersome and difficult to do accurately. This fact probably accounts for the variation of the power readings which were obtained and their rather poor correlation with the observed hyperthermia.

When the bandwidth control on the modulator panel was placed in the "zero" position or the thyratron, gas triode tube (JAN-6D4), was removed from the modulator, an unmodulated carrier wave is emitted. Under these conditions the transmitter operates CW (continuous wave). These are the conditions under which series 3 experiments were performed. The carrier frequency was 356.7 Mc and was unmodulated. It was felt that a comparison should be made between this continuous wave emission and the pulsed wave of previous experiments for, although the average power output in both instances is of the same magnitude, the peak power output of the pulsed emission is manyfold that of the CW signal.

During the series 2 experiments the transmitter was operated at a carrier frequency of 287.4 Mc (Average), noise modulated. This was the lower limit of the frequency at which the wave guide maintained a normal power output. However, tuning of the antenna was virtually impossible, as it was extended to its maximum excursion. For this reason, it is assumed that the power output figures are not reliable. The quality of resonance obtained during the course of these experiments must also have been inferior and consequently, one might expect to find a decreased thermic effect on these experimental animals.

The Results

1. Introduction

The analysis of the data of this investigation is divided primarily into two groups: (I) the investigations of the heating rate of saline, and (II) the investigations of the heating of living rabbits. The latter investigations are divided into three sub-groups: (A) those conducted in the decompression chamber, (B) those conducted in the waveguide, but without adequately accurate temperature records, and (C) those conducted in the waveguide with temperatures obtained with the use of thermocouples. The latter subgroup is further divided into three series: (1) those exposed to radiation of a frequency of about 358 Mc, noise modulated with a band width of 5 Mc; (2) those exposed to radiation of a frequency of about 290 Mc, noise modulated - bandwidth 5 Mc; and (3) those exposed to radiation of a frequency of 258 Mc without modulation. In the analysis of temperature data, subgroup (B) is not included although the conditions of the experiment were the same as for series (1) of subgroup (C) and therefore, these data are combined in the discussions of mortality and exposure.

The pathological changes produced by these modalities are discussed and compared. The comparative effect of modulated and unmodulated high frequency radio waves of the wavelengths used in this experiment is also considered.

2. Group I - Rate of Heating of Saline

Two experiments were conducted in an attempt to demonstrate the concentration of saline which would heat most rapidly at the frequency (approx. 355 Mc) which would later be used in animal experiments. This was also the frequency which previous work by other investigators had indicated to be the frequency which could be expected to produce maximum heating in isotonic saline. In these two experiments the operating conditions of the transmitter varied slightly and, consequently, would be expected to have somewhat different power outputs. The operating data are given in the following table:

TABLE I

	#1	#2
Modulator Voltage (v)	700	620
Oscillator Voltage (v)	1375	1375
Mod. Plate Current (ma.)	400	400
Grid Current (ma.)	14.0	16.0
Frequency dial setting	1300	1300
Coupling dial	300	300

These data indicate that the power output in experiment No. 1 was somewhat greater than in No. 2, and therefore, the rate of heating would be expected to be somewhat greater. This fact is borne out in the following table:

TABLE 2

Concentration (%)	Initial #1	Initial #2	5 Minutes #1	5 Minutes #2	10 Minutes #1	10 Minutes #2
0	25.0°C	21.0°C	25.0°C	21.0°C	25.5°C	21.5°C
0.10	23.0	22.0	25.0	24.0	26.5	26.0
0.25	22.0	22.0	26.0	26.0	31.0	30.0
0.40	22.5	22.0	31.0	25.5	41.0	31.0
0.55	22.0	22.0	33.5	28.5	45.5	37.0
0.70	22.0	22.0	35.0	28.5	46.0	37.0
0.85	22.0	22.0	34.0	31.0	49.0	42.5
1.00	22.0	22.0	37.0	30.0	53.0	40.0
1.15	22.0	22.0	34.0	29.5	47.0	41.0
1.30	22.0	22.0	34.5	29.0	47.5	38.5
1.45	22.5	21.0	36.5	28.0	50.0	35.5

These data seem to verify the supposition that a frequency of about this magnitude is one which will produce maximum heating in saline with concentrations of approximately 0.85-1.0%.

A third experiment was run under similar conditions to determine the time of exposure necessary to bring an isotonic solution of saline to the boiling point. It was determined that 180 cc of solution could be brought from 29°C to an active boil in 17 minutes. This information was thought pertinent in determining the length of exposure to subject animals later. It was, of course, realized that under the conditions of this experiment there was relatively little loss of heat by conduction, convection, or radiation as would occur in the animal experiments.

3. <u>Group II - Heating of Mammalian Tissue (Rabbit)</u>

<u>Subgroup A - Cone Antenna Experiment</u>

Seven experiments were performed in which five animals were used for each experiment. There were no fatalities and apparently no lasting ill effects. During the exposure all animals developed a moderate hyperthermia, became moderately hyperpneic, some became quite lethargic. Recovery was usually complete within a few hours after termination of exposure.

The following table shows the range of rectal temperatures recorded in this group of experiments. These temperatures may be inaccurate since they were taken with clinical rectal thermometers and at times following exposures varying up to ten minutes. The results indicate only that energy was absorbed in sufficient quantities to produce measurable systemic effects under the conditions of the experiment. There were no fatalities.

TABLE 3

Exp. No.	Modulator Voltage (V)	Plate Current	Oscillator Voltage (V)	Temperature Difference °C -1	-2	-3	-4	-5	C-4	C-5
1-2:00	550	400	1500	-*	-*	-*	-*	-*		
2-2:00	550	400	1500	1.2	1.0	1.1	2.1	1.3		
3-2:00	500	400	1500	0.5	0.9	0.8	0.8	1.6		
4-2:00	550	400	1500	0.7	0.5	0.6	0.4	0.9		
5-1:30	550	400	1625	0.5	0.3	0.4	0.4	0.7		
6-2:00	550	400	1625	0.5	0.8	0.8	0.6	0.5		
7-1:30	550	400	1500	0.6	1.0	0.8	--	--	0.7	0.9

* Pre-exposure temperatures were not taken in this experiment but the post exposures temperatures were of the same magnitude as for the succeeding experiments, i.e., 39.7, 40.6, 39.9, 40.3, and 40.3°C, respectively.

One experiment was performed in which the cone antenna was placed 15 cm from the eyes of a rabbit (C-1). The animal was unanesthetized, immobilized, and exposed for a period of twenty minutes. During the exposure the rabbit became quite stuporous, the eyes appeared glassy, discharged profusely, but remained open. The systemic (rectal) temperature rose only $0.3^{\circ}C$ during the exposure. Recovery appeared complete within one hour. Subsequent ophthalmoscopic examinations failed to reveal any abnormalities of the ocular media. The operating characteristics of the transmitter during this experiment are given in the following table:

Modulator Plate voltage (volts)	- 550
Modulator Plate Current (ma.)	- 400
Oscillator Voltage (volts)	- 1000

<u>Subgroup B - Waveguide Experiments (Frequency 358 Mc, noise modulated, 5 Mc bandwidth, clinical and toluene thermometers)</u>

Fourteen experiments were performed, making a total of twenty-seven animal exposures, some of the animals being used more than once. Of this group there were five deaths following exposure, all deaths occurred within twenty-four hours after removal from exposure. All animals developed a hyperthermia to varying degrees, breathing became rapid and deep, profuse lacrymal discharge was usually noted, frequently a profuse diarrhea developed during exposure which was characterized by its muco-fecal character. No evidence of blood was ever noted. Frequently in those rabbits which developed extreme hyperthermia and hyperpnea and later dyspnea, loud coarse rales were clearly audible over the entire lung fields even without the aid of a stethescope. In the cases terminating fatally within an hour after removal from exposure, the picture was that of terminal clonic convulsions, and, finally, death with cyanosis, breathing having become slow and shallow just prior to death. Some of the animals who survived developed much the same picture and were completely paralyzed immediately following exposure. Complete recovery in these cases was noted within twenty-four hours.

The operating data of the transmitter is given in table (4).

<u>Subgroup C - Waveguide Experiments</u>

Transmitter Data - The transmitter data and wattmeter data are tabulated in tables 5, 6, and 7 for each of the three series of this subgroup. As will readily be seen, "absorbed power" is merely the difference between the power output before and the power output during the exposure. The power output prior to exposure in the three series follows relatively what one

Table 4

TRANSMITTER DATA

	Date	Identif. Number	Duration	Mod V (Volts)	Osc V (Volts)	Pl Cur (ma)	Grid Cur (ma)	Before	During	Absorbed
1)	24 Jul 50	x-1,x-2	20	300-560	1425-1700	200-280	13.0-13.2	88-94	40-63	48-31
2)	25 Jul 50	x-3,x-4*	20	750	1300	370	13.6	131	59	72
3)		x-1,x-2	20	650	1400	370	13.6	128	72	56
4)	26 Jul 50	x-1,x-2	20	650	1400	380	13.6	128	72	56
5)		x-3*,x-5	20	640	1400	370	13.6	128	67	61
6)	27 Jul 50	x-1,x-2	20	650	1375	380	14.0	127	62	65
7)		x-5	20	650	1375	380	14.0	125	88	37
8)	28 Jul 50	x-1,x-2	20	650	1375	370	13.8	131	52	79
9)		x-5,c-1	20	700	1350	440	16.0	126	55	71
10)	29 Jul 50	x-1,x-2	20	650	1375	410	16.0	130	58	72
11)		x-5,c-1	20	660	1350	410	16.0	135	58	77
12)	31 Jul 50	x-1,x-2	20	650	1375	420	16.0	126	60	66
13)		x-5,c-1*	20	600	1450	420	16.0	131	58	73
14)	2 Aug 50	c-4*,x-2*	36	650	1400	430	16.0	120	71	49

Note:

*x-4 died 26 July (cervical abscess)
*x-3 died 27 July
*c-4, x-2 - died immediately following exposure - 2 Aug 50
*c-1 died 20 min. after exposure - 31 Aug 50

Table 5

TRANSMITTER DATA (SERIES-1)

	Date	Identif Number	Duration	Mod V (Volts)	Osc V (Volts)	Pl Cur (ma)	Grid Cur (ma)	Before	During	Absorbed
1)	10 Aug 50	x-1,x-5	20.0	640	1450	440	16.4	123	71	52
2)	14 Aug 50	x-1,x-5	20.0	680	1375	440	16.2	112	66	46
3)		x-6,x-7	7.5	680	1375	440	16.4	130	96	34
4)		x-8,x-9	15.0	620	1450	420	16.2	126	104	22
5)	15 Aug 50	c-2,c-3*	25.0	650	1400	440	16.2	123	66	57
6)	16 Aug 50	x-1,x-5	21.0	680	1350	420	16.0	120	58	62
7)		x-8,x-9	25.0	640	1425	440	16.2	136	82	54
8)	17 Aug 50	x-6,x-7	15.0	660	1400	430	16.2	123	77	46
9)		c-2	10.0	640	1400	440	16.2	137	101	36
10)	18 Aug 50	x-8,x-9*	32.0	660	1375	430	16.2	127	93	34
11)	21 Aug 50	c-2*,x-8	25.0	640	1425	440	16.2	172	104	68
12)	12 Sep 50	x-20,x-21	25.0	650	1425	400	14.8	162	108	54
13)		x-22,x-23	20.0	650	1425	400	14.2	158	108	50
14)	15 Sep 50	x-10,x-12	30.0	650	1450	400	14.2	155	100	55
15)		x-1*	27.0	650	1425	400	14.8	155	94	61
16)		x-24*	24.0	650	1425	400	14.6	155	117	38

*Died immediately following this exposure

Table 6

TRANSMITTER DATA (SERIES-2)

Date	Identif Number	Duration	Mod V (Volts)	Osc V (Volts)	Pl Cur (ma)	Grid Cur (ma)	Before	During	Absorbed
1) 24 Aug 50	x-10,x-11	15	630	1475	400	15.0	200	123	77
2)	x-12,x-13	20	630	1450	400	15.0	200	130	70
3)	x-14,x-15	25	660	1400	410	15.2	200	130	70
4) 25 Aug 50	x-10,x-11	15	650	1450	400	14.4	208	130	78
5)	x-12,x-13	20	650	1500	400	14.4	200	145	55
6)	x-14,x-15	25	650	1425	400	14.2	200	138	62
7) 28 Aug 50	x-10,x-11	15	650	1450	390	14.4	204	130	74
8)	x-12,x-13	20	650	1450	400	14.6	200	130	70
9)	x-14,x-15	25	650	1400	400	14.2	200	123	77
10) 29 Aug 50	x-10,x-11	20	650	1400	400	14.0	200	143	57
11)	x-12,x-13	20	650	1450	400	14.6	204	141	63
12)	x-14,x-15	31.5	650	1475	400	14.4	204	143	61
13) 30 Aug 50	x-10,x-11	21	650	1475	400	14.6	200	145	55
14)	x-12,x-13	20	650	1450	400	14.4	200	145	55
15)	x-14,x-15	31	650	1450	390	14.4	200	138	62
16) 31 Aug 50	x-10,x-11	15	650	1475	400	14.4	202	146	56
17)	x-12,x-13	20	650	1450	400	14.4	200	136	64
18)	x-14,x-15	35	650	1475	400	14.4	200	140	60
19) 1 Sep 50	x-10,x-15	40	650	1450	400	14.4	208	140	68

Table 7 TRANSMITTER DATA (SERIES-3)

	Date	Identif Number	Duration	Mod V (Volts)	Osc V (Volts)	Pl Cur (ma)	Grid Cur (ma)	Before	During	Absorbed
1)	7 Sep 50	x-20,x-21	15	550	1300	400	0	176	108	68
2)		x-22,x-23	20	550	1375	390	0	172	114	58
3)	8 Sep 50	x-24,x-25	25	560	1375	390	0	168	108	60
4)		x-20,x-21	15	640	1400	460	0	196	134	62
5)		x-22,x-23	20	640	1375	450	0	192	132	60
6)	11 Sep 50	x-24,x-25	25	650	1375	450	0	196	126	70
7)		x-20,x-21	15	650	1375	450	0	196	124	72
8)		x-22,x-23	20	650	1375	450	0	190	126	64
9)	12 Sep 50	x-24,x-25	25	650	1375	450	0	190	130	60
10)	15 Sep 50	x-25	25	650	1375	400	0	172	134	38

would expect from the rated output at the different frequencies used, i.e., the output for series (2) should be relatively higher than for the other two series. However, the actual figures are higher than the rated output in all cases by 30-50 watts. This difference may be due to the use of the waveguide in place of the conventional antenna. However, when the transmitter was connected directly to the wattmeter and this reading compared to that obtained when the antenna lead was connected to the waveguide, the difference was only of the order of about two watts loss through the guide.

The ratio of absorbed power per kilo of body weight would be expected to be fairly constant provided the means of measuring this power were accurate. A perusal of table 9 quickly indicates that such is not the case. Although there certainly are differences in individual rabbits from a chemical composition standpoint, especially with increasing age and size, it does not seem reasonable that these differences should be so great. It certainly does not allow one to predicate the temperature rise on the power absorbed and the time of exposure.

Series (1) : The results of this series of experiments are tabulated in table 8 in the chronological order in which they were done. The weights as given in column 3 are recorded as of the day they were done and, consequently, do not appear each time a given animal was exposed, the whole series extended over a period of only six days. The temperature rise is given for each animal separately and also as a combined rise when two animals were exposed simultaneously. A consolidation of this data appears in table 9 arranged in order of increasingly longer exposure periods. It will be noted that five animals died following exposure to this radiation, two of these animals being exposed individually, the other three each being one of a pair of exposed partners. It will be noted that with one exception the peak temperatures of those terminating fatally reached to points higher than 44.6°C. The exception (X-9) reached a peak of 41.2°C, a rise of only 2.6°C from its pre-exposure level. This animal died about two hours after exposure. The rectal temperatures during the recovery phase gradually returned to normal levels

Table 8

TEMPERATURE DATA (SERIES-1)

Date	Identif. Number	Wt.	Duration	Temperature (°C) Pre Exp.	Post Exp	Temperature Difference (Rise)	Combine T
1) 10 Aug 50	(x-1	4780)	20	39.8	42.1	2.3	
	(x-5	3965)		40.3	41.6	1.3	
2) 14 Aug 50	(x-1	4556)	20	40.8	41.8	1.0	3.6
	(x-5	3965)		39.6	42.0	2.4	
3)	(x-6	2117)	7.5	39.9	40.2	0.3	3.4
	(x-7	2096)		39.7	39.8	0.1	
4)	(x-8	2015)	15.0	39.8	40.4	0.6	0.4
	(x-9	1860)		39.8	41.8	2.0	
5) 15 Aug 50	(c-2	4575)	25.0	41.1	42.7	1.6	2.6
	(c-3*	4980)		41.4	44.6	3.2	
6) 16 Aug 50	(x-1	)	21	41.0	41.8	0.8	4.8
	(x-5	)		40.4	41.6	1.2	
7)	(x-8	)	25	41.0	43.8	2.8	2.0
	(x-9	)		40.9	42.7	1.8	
8) 17 Aug 50	(x-6	)	15	41.0	42.6	1.6	4.6
	(x-7	)		41.0	42.7	1.7	
9)	c-2		10	40.8	42.1	1.3	3.3
	(x-8	)	32	38.4	40.5	2.1	1.3
10) 18 Aug 50	(x-9*	)		38.6	41.2	2.6	
11) 21 Aug 50	(c-2*	4502)	25	40.2	44.8	4.6	4.7
	(x-8	2165)		41.0	41.3	0.3	4.9

Table 8A

TEMPERATURE DATA CONTINUED (SERIES-1)

Date	Identif. Number	Wt.	Duration	Temperature (°C) Pre Exp.	Temperature (°C) Post Exp.	Temperature Differences (Rise)	Combined T
12) 12 Sep 50	(x-20	2271)	25	40.6	42.0	1.4	
	(x-21	2120)		40.2	41.9	1.7	3.1
13)	(x-22	2139)	20	40.2	40.9	0.7	
	(x-23	2317)		40.4	41.4	1.0	1.7
14) 15 Sep 50	(x-10	2605)	30	40.3	41.9	1.6	
	(x-12	2655)		39.5	41.4	1.9	3.5
15)	x-1*	3485	27	40.4	46.1	5.7	5.7
16)	x-24*	2317	24	41.1	45.3	4.2	4.2

*Died following this exposure

Table 9 - RELATIONSHIP OF DURATION OF EXPOSURE TO TEMPERATURE RISE, TOTAL WEIGHT, AND ABSORBED POWER

Duration (Min)	Combined Temp.Rise (°C)	Tot.Wt.(gms)	Power Absorp.	(Watts) W/Kilo
7.5	0.4	4213	34	8.95
10.0	1.3	4980	36^{-3}	7.23
15.0	2.6	3875	22	5.68
	3.3	4213^{-2}	46	10.91
20.0	3.6	8745	52	5.88
	3.4	8521	46	5.40
	1.7	4456	50	11.2
21.0	2.0	8521^{-2}	62	7.28
24.0	4.2^{-1}	2317	38^{-3}	16.40
25.0	4.8^{-1}	9555	57	5.96
	4.6	3875^{-2}	54	13.9
	4.9^{-1}	6667	68	10.2
	3.1	4391	54	12.3
27.0	5.7^{-1}	3845	61^{-3}	17.5
30.0	3.5	5260	55	10.45
32.0	4.7^{-1}	3875	34	8.76

1. One animal died following exposure

2. Weight taken as of a previous determination

3. One animal exposed alone

in little more than an hour. Death occurred with convulsions as in the other cases.

<u>Series (2)</u> : The data accumulated in this series is recorded in tables <u>10</u> and <u>11</u> in a similar manner to those from Phase (1). Although the duration of exposure in some cases exceed those from the previous series, the peak temperatures attained never exceeded 43.5°C. This very likely accounts for the absence of any fatalities in this series. The average frequency used during this series was 287.4 Mc (282.8 - 292.0 Mc). A few of the animals reaching comparatively high temperatures demonstrated findings similar to those of the previous series, i.e., hyperpnea, increased intestinal activity but neither diarrhea, increased lacrymation, nor increased salivation. None of the animals appeared as toxic as those reaching correspondingly high temperatures in the previous series.

<u>Series (3)</u> : The data of this series is included in tables <u>12</u> and <u>13</u> and arranged similarly to those of the two previous series. It will be noted that there were no fatalities in this series and that

Table 10 TEMPERATURE DATA (SERIES-2)

Date	Identif. Number	Weight (gms)	Duration	Temperature (°C) Pre Exp.	Temperature (°C) Post Exp.	Temperature Difference (Rise)	Combined T
1) 24 Aug 50	(x-10	2043	15	41.2	42.4	1.2	
	(x-11	2041		40.5	41.2	0.7	1.9
2)	(x-12	2087	20	40.7	42.2	1.5	
	(x-13	2120		40.9	42.8	1.9	3.4
3)	(x-14	2069	25	40.8	42.6	1.8	
	(x-15	2185		40.9	42.7	1.8	3.6
4) 25 Aug 50	(x-10		15	41.2	41.5	0.3	
	(x-11			41.9	42.4	0.5	0.8
5)	(x-12		20	40.9	42.2	1.3	
	(x-13			41.0	42.3	1.3	2.6
6)	(x-14		25	41.0	42.4	1.4	
	(x-15			40.6	41.6	1.6	3.0
7) 28 Aug 50	(x-10		15	40.4	41.2	0.8	
	(x-11			40.5	41.4	0.9	1.7
8)	(x-12		20	41.0	41.9	0.9	
	(x-13			41.1	42.6	1.5	2.4
9)	(x-14		25	40.4	41.6	1.2	
	(x-15			40.9	41.7	0.8	2.0

Table 10 Continued TEMPERATURE DATA (SERIES-2)

Date	Identif. Number	Weight (gms)	Duration	Temperature (°C) Pre Exp.	Post Exp.	Temperature Difference (Rise)	Combined T
10) 29 Aug 50	(x-10	2259)	20	41.0	41.9	0.9	
	(x-11	2220)		41.1	42.1	1.0	1.9
11) 29 Aug 50	(x-12	2376)	20	40.5	41.4	0.9	
	(x-13	2171)		41.3	42.3	1.0	1.9
12)	(x-14	2514)	31.5	40.5	43.5	3.0	
	(x-15	2265)		40.4	42.1	1.7	4.7
13) 30 Aug	(x-10	)	21	40.3	41.3	1.0	
	(x-11	)		41.0	42.5	1.5	2.5
14)	(x-12	)	20	40.5	41.3	0.8	
	(x-13	)		40.8	41.7	0.9	1.7
15)	(x-14	)	31	40.8	43.3	2.5	
	(x-15	)		40.7	42.7	2.0	4.5
16) 31 Aug 50	(x-10	)	15	41.2	41.7	0.5	
	(x-11	)		41.4	42.5	1.1	1.6
17)	(x-12	)	20	40.7	41.5	0.8	
	(x-13	)		41.2	42.0	0.8	1.6
18)	(x-14	)	35	40.7	43.0	2.3	
	(x-15	)		39.9	41.7	1.8	4.1
19) 1 Sep 50	(x-10	)	40	41.4	43.3	1.9	
	(x-15	)		41.2	42.8	1.6	3.5

Table 11 - POWER ABSORPTION RATIO (WATTS/KILO)

Duration	Combined Temp Rise (°C)	Tot.Wt.(gms)	Power Absorp.	Power Absorp. W/Kilo
15	1.9	4084	77	18.85
	0.8		78	19.1
	1.7		74	18.1
	1.6	4479	56	12.5
20	3.4	4207	70	16.65
	2.6		55	13.1
	2.4		70	16.65
	1.9	4479	57	12.7
	1.9	4547	63	13.9
	1.7	(4479)	55	12.3
	1.6	(4547)	64	14.1
21	2.5	(4479)	55	12.3
25	3.6	4254	70	16.4
	3.0		62	14.6
	2.0		77	18.1
31-31.5	4.5	4779	62	13.0
	4.7		61	12.8
35	4.1		60	12.6
40	3.5	4524	68	15.1

Table 12

TEMPERATURE DATA

	Date	Identif. Number	Weight (gms)	Duration	Temperature (°C) (Rectal) Pre.Exp.	Post Exp.	Temp. Difference (Rise)	Comb.
1)	7 Sep 50	(x-20	2271	15	41.4	42.5	1.1	
		(x-21	2120		41.5	42.8	1.3	2.4
2)		(x-22	2250	20	40.7	42.4	1.7	
		(x-23	2139		41.0	42.8	1.8	3.5
3)	8 Sep 50	(x-24	2317	25	40.7	42.8	2.1	
		(x-25	2074		40.7	42.6	1.9	4.0
4)		(x-20	)	15	40.6	42.7	2.1	
		(x-21	)		40.8	42.4	1.6	3.7
5)		(x-22	)	20	40.5	41.9	1.4	
		(x-23	)		40.5	42.9	2.4	3.8
6)	11 Sep 50	(x-24	)	25	40.8	43.4	2.6	
		(x-25	)		41.1	42.5	1.4	4.0
7)		(x-20	)	15	41.2	43.0	1.8	
		(x-21	)		41.3	43.0	1.7	3.5
8)		(x-22	)	20	40.5	41.8	1.3	
		(x-23	)		40.8	42.2	1.4	2.7
9)	12 Sep 50	(x-24	)	25	40.5	42.8	2.3	
		(x-25	)		40.4	42.2	1.8	4.1
10)	15 Sep 50	(x-25		25	40.1	42.7	2.6	2.6

Table 13 POWER ABSORPTION RATIOS

Duration	Combined Temp. Rise (°C)	Tot.Wt.(gms)	Power Absorp.	Power Absorp. W/Kilo
15	2.4	4391	68	15.5
	3.7		62	14.1
	3.5		72	16.4
20	3.5	4389	58	13.2
	3.8		60	13.7
	2.7		64	14.6
25	4.0	4391	60	13.7
	4.0		70	15.95
	4.1		60	13.7
	2.6	(2074)	38	18.3

the highest peak temperature reached was 43.4°C, although none of the exposures exceeded a period of twenty-five minutes. The reactions of the animals were essentially the same as for the previous series in respect to hyperpnea, lacrymation, and salivation.

4. Comparison of Temperature Effects

The comparison of the average peak temperatures at various durations of exposure under the experimental conditions of the three series used is given in table 14. Similarly the average combined temperature rise is compared with the durations of exposure and appears in table 15. From these statistics alone it is not possible to conclude that there is any essential difference in the absorption of electromagnetic radiation of the frequencies concerned, because the differences either in peak temperatures or in the average temperature rise are not of statistical significance at any given duration of exposure. The range from which these averages are obtained has considerably too much spread and even if one could also correct for the variations in animal weight and the power output, he would also have the problem of individual variations in physiological mechanisms and their ability to dissipate the absorbed heat energy. Such correlations have not been attempted in this study because it was felt that the measurement of power output as recorded is too inaccurate.

Table 14 DISTRIBUTION OF PEAK TEMPERATURES BY DURATION OF EXPOSURE

Duration	Series 1	No Animals	Av (^{o}C)	Series 2	No Animals	Av (^{o}C)	Series 3	No Animals	Av (^{o}C)
5-9	39.2-40.2	(2)	39.7						
10-14	42.1	(1)	42.1						
15-19	40.4-42.7	(4)	41.88	41.2-42.5	8	41.79	42.4-43.0	6	42.73
20-24	40.9-45.3	(9)	42.05	41.3-42.8	16	42.00	41.8-42.9	6	42.33
25-29	41.3-46.1	(9)	43.32	41.6-42.7	6	42.10	42.2-43.4	7	42.71
30-34	40.5-41.9	(4)	41.25	42.1-43.5	4	42.90			
35-39				41.7-43.0	2	42.35			
40				42.8-43.3	2	43.05			

Table 15

AVERAGE TEMPERATURE RISE
(Combined - both Single and Paired)
in Relation to Duration of Exposure

Duration (min)	No. Exp.	Series 1 Range (°C)	Av(°C)	No Exp.	Series 2 Range (°C)	Av (°C)	No Exp	Series 3 Range (°C)	Av (°C)
5-9	1		0.40						
10-14	1		1.30						
15-19	2	2.6-3.3	2.95	4	0.8-1.9	1.50	3	2.4-3.7	3.20
20-24	5	1.7-4.2	2.98	8	1.6-3.4	2.25	3	2.7-3.8	3.33
25-29	5	3.1-5.7	4.62	3	2.0-3.6	2.87	4	2.6-4.1	3.68
30-34	2	3.5-4.7	4.10	2	4.5-4.7	4.60			
35-39				1		4.10			
40 +				1		3.50			

5. Mortality Rates

The mortality rates are tabulated in table 16. Series (1) and subgroup B are included as one, since the conditions of the twoexperiments were essentially identical. This is the only group in which any fatalities were noted, although series (3) did not include some exposures which were aslong as those in the other two series. Whether the absence of fatalities in the twoexposures in series (3) of 20-24 and 25-29 minutes duration is significant is questionable, although it appears likely that the pulsed radiation may result in greater absorption of energy than the continuous wave radiation, as shown in the comparison of series (1) and series (3). Series (2) represents an experimental condition in which optimum resonance was not attained and, consequently, one would not expect as efficient an absorption of energy as in the other two series.

Table 16

Duration	Group B and Series 1				Series 2				Series 3			
	No. Exp.	No. Anim.	No. Deaths	Per Cent	No. Exp.	No. Anim.	No. Deaths	Per Cent	No. Exp.	No. Anim.	No. Deaths	Per Cent
5-9	1	2	0	-								
10-14	1	1	0	-								
15-19	2	4	0	-	4	8	0		3	6	0	
20-24	18	34	4	11.8	8	16	0		3	6	0	
25-29	5	9	3	33.0	3	6	0		4	7	0	
30-34	2	4	1	25.	2	4	0					
35-39	1	2	2	100.	1	2	0					
40					1	2	0					
	Group B Only											
20-24	13	25	3	12.								
35-39	1	2	2	100.								

Abbreviations: Exp - Exposures
Anim - Animals

Table 17

EXPOSURE RECORD - ALL EXPERIMENTAL ANIMALS

Identif.	Subgroup A		Subgroup B		Subgroup C Series 1		Subgroup C Series 2		Subgroup C Series 3		Tot. Dura. Exp.	Died or Kill.	Tot. No. Exp.
	No. Exp.	Tot. Dura.	No. Exp.	Tot. Dura.	No. Exp.	Tot. Dura.	No. Exp.	Tot. Dura.	No. Exp.	Tot. Dura.			
x-1	7	13:07	7	2:20	4	1:28					16:15	D	18
x-2	7	13:07	8	2:56*							16:03	D	15
x-3	7	13:07	2	0:40*							13:47	D	9
x-4	6	11:37	1	0:20*							11:57	D	7
x-5	6	11:37	5	1:40	3	1:01					14:18	K	14
x-6					2	0:22					0:22		2
x-7					2	0:22					0:22	K	2
x-8					4	1:35					1:35	K	4
x-9					3	1:10*					1:10	D	3
x-10					1	0:30	7	2:21			2:21		8
x-11							6	1:41			1:41	K	6
x-12					1	0:30	6	2:00			2:30		7
x-13							6	2:00			2:00	K	6
x-14							6	2:52			2:52		6
x-15							7	3:32			3:32	K	7
x-20					1	0:25			3	0:45	1:10		4
x-21					1	0:25			3	0:45	1:10		4
x-22					1	0:20			3	1:00	1:20	K	4
x-23					1	0:20			3	1:00	1:20		4
x-24					1	0:24*			3	1:15	1:39	D	4
x-25									3	1:35	1:35		3

Table 17 (Continued) EXPOSURE RECORD - ALL EXPERIMENTAL ANIMALS

	Subgroup A		Subgroup B		Subgroup C Series 1		Subgroup C Series 2		Subgroup C Series 3				
Identif.	No. Exp.	Tot. Dura.	No. Exp.	Tot. Dura.	No. Exp.	Tot. Dura.	No. Exp.	Tot. Dura.	No. Exp.	Tot. Dura.	Tot. Dura Exp.	Died or Kill.	Tot. No. Exp.
c-1	1	0:20	3	1:00*							1:20	D	4
c-2					3	1:00*					1:00	D	3
c-3					1	0:25					0:25	D	1
c-4	1	1:30	1	0:36*							2:06	D	2
c-5	1	1:30*									1:30	D	1

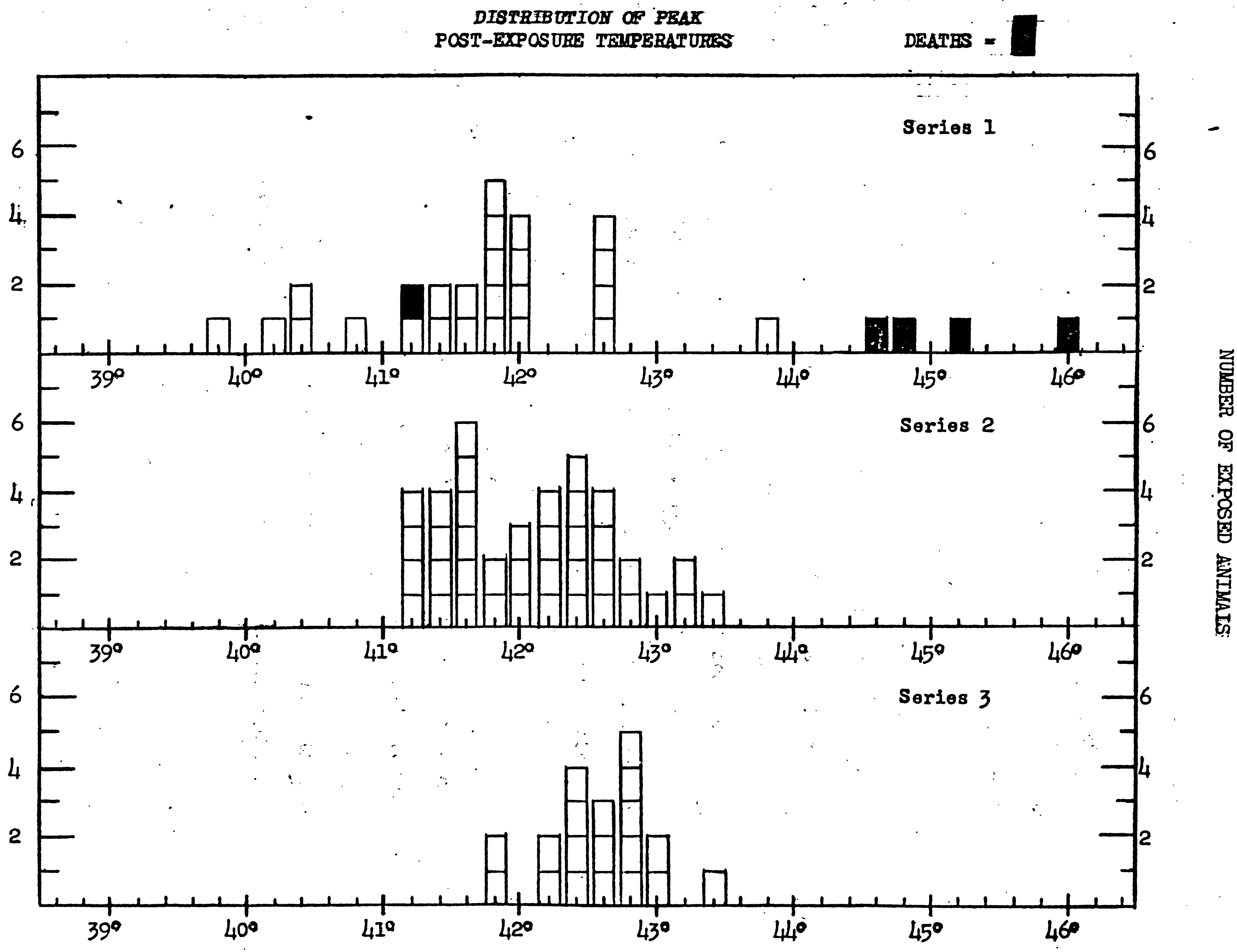
Note: *Died following exposure indicated

Table 18

SUMMARY OF AUTOPSIED ANIMALS

Identif.	Last Exposure			Killed (k) Died (d)	Date of Death	Interval Last Exp - Death
	Type	Duration	Date			
x-1	C-1	27 min.	15 Sep 50	D	15 Sep 50	0
x-2	B	36 "	2 Aug 50	D	2 Aug 50	0
c-4	C-1	36 "	2 Aug 50	D	2 Aug 50	0
x-24	C-1	24 "	15 Sep 50	D	15 Sep 50	0
c-1	B	20 "	31 Jul 50	D	31 Jul 50	0
x-9	C-1	30 "	18 Aug 50	D	18 Aug 50	0
c-2	C-1	25 "	22 Aug 50	D	22 Aug 50	0
c-3	C-1	25 "	15 Aug 50	D	15 Aug 50	0
c-5	A	1hr.30min.	8 Feb 50	D	28 May 50	109 days
x-5	C-1	21 min.	16 Aug 50	K	31 Aug 50	15 "
x-15	C-2	40 "	1 Sep 50	K	2 Sep 50	1 day
x-13	C-2	20 "	31 Aug 50	K	2 Sep 50	2 days
x-11	C-2	15 "	31 Aug 50	K	2 Sep 50	2 "
x-8	C-1	24 "	21 Aug 50	K	31 Aug 50	10 "
x-22	C-1	20 "	1 Sep 50	K	31 Oct 50	61 "
x-7	C-1	15 "	17 Aug 50	K	31 Aug 50	14 "

DISTRIBUTION OF PEAK
POST-EXPOSURE TEMPERATURES



The distribution of peak temperatures is shown in graph 1 and demonstrates that lethal temperatures for the rabbit are those probably in excess of about 44.5°C, although this does not explain the reasons for the death of the one rabbit whose temperature reached only a peak of 41.2°C.

A tabulation of the exposures of each animal used in the experiment may be found in table 17. The total number of exposures is indicated, in terms of hours: minutes, as well as the duration of exposure.

The animals which were subjected to post-mortem studies are listed in table 18, which gives a more detailed account of the last exposure as to both duration and type. It also indicates the time interval between the last exposure and the date of autopsy.

6. Pathological Changes

Two animals (X-3, X-4) have not been included in this discussion because of the extensive pathological changes due to other causes.

The pathological changes noted were essentially the same in respect to the type of radiation to which the animals were exposed, i.e., there was no detectable difference between those animals exposed to the modulated carrier (pulsed) and those exposed to the unmodulated carrier (CW).

Central Nervous System - Although there were no gross changes visible, all animals exhibited microscopic evidence of diffuse degeneration of the Purkinji cells and of the neurons of the cerebral cortex, the nuclei of the spinal nerves of the pons, the medulla, and in a few cases of the cerebellum. In X-8 this degeneration was focal in nature. These changes were evident in all cases including those killed fourteen and sixty-one days after the last exposure, as well as the one dying after one-hundred-nine days, and this leads one to believe that the damage occurred at the time of exposure, and there was little or no recovery.

Cardio-vascular System - In those animals dying shortly after exposure, gross hemorrhagic areas were noted in the myocardium in about 25% of the animals. In all except X-8 there was noted a diffuse degeneration of myocardial fibers, manifested by loss of striations, pyknosis of the nuclei and, in some, vacuolization of the myocardial fibers. The degree of damage varied considerably but bore no detectable relationship to the type of radiation.

Respiratory Tract - Grossly, all animals dying immediately after exposure, demonstrated submucosal hemorrhages of the trachea which were usually quite extensive. Some cases had gross evidence of intrapulmonary hemorrhage, and pulmonary edema. Microscopically, there was marked hyperemia, edema and extravasation of erythrocytes into the submucosa of the trachea in most cases. Pulmonary edema, and intra-alveolar and subpleural hemorrhages were noted in all cases of this group. Animal (X-5) which died 109 days following exposure also showed a marked hyperemia of the pulmonary vessels which were filled with neutrophils and eosinophils. This finding appeared to be consistent with an acute interstitial pneumonitis which was probably the immediate cause of death. (X-22), killed sixty-one[1] days after the last exposure, also had a hyperemia of pulmonary alveolar capillaries with marked infiltration of these capillaries with granulocytes. (X-13) had a confluent lobular pneumonia when it was killed the day following the last exposure.

Gastro-intestinal Tract - In the group of animals dying shortly after exposure, the intestinal tract, especially the jejunum and ilium, showed gross evidence of rather severe, multiple but localized areas of hemorrhages, which appeared to extend through the entire wall of the intestine. Microscopically, the changes varied from hyperemia and hemorrhage into the mucosa to frank necrosis of the mucosal epithelium. (X-24) also had a fibroblastic reaction within the mucosal tissues. The appendix of this animal also had a marked hyperplasia of the lymphoid cells of the surface mucosa and of the granulocytes within the mucosa. (C-5) had a slight necrosis of the superficial epithelial cells of the jejunal mucosa, death having occurred one-hundred-nine days after exposure. The animals which were killed for post-mortem studies failed to demonstrate any pathological changes of the g.i. tract.

Liver - The tips of the lobes of the liver of those animals examined immediately after exposure were usually grayish in color. Microscopically, the changes varied considerably from a mild to a moderate degeneration of the hepatic cells. Focal cell necrose also was found. In some cases there was also necrosis of the granulocytes and lymphocytes in the lumena of the hepatic vessels. (C-5) dying one-hundred-nine days after exposure had a fatty vacuolization and focal hyaline necrosis of the hepatic cells indicating that some attempt at repair had taken place. There was no evidence of damage in the livers of (X-7 and X-8). These animals were killed fourteen and ten days after the last exposure, respectively. There was only slight damage in the liver of (X-5) killed fifteen days after exposure but there was a moderately diffuse parenchymatous degeneration of the hepatic cells of (X-22) killed sixty-one days after exposure.

Spleen - Grossly all spleens appeared quite normal. Microscopically, most cases showed some evidence of hyperemia, and occasionally, a focal necrosis of lymphocytes and some granulocytes in the sinusoids as well as in the follicles. (X-7) had a splenic hyperplasia and there was also evidence of hemopoiesis. There was a marked hyperemia of the spleen of (C-5).

Kidneys - Grossly many of the animals dying immediately after exposure demonstrated a grayish cast to the capsule of the kidneys. The most constant finding found in all animals was a degeneration of the epithelial cells lining the proximal and the distal convoluted tubules of the kidney. The severity varied somewhat but was most marked in (C-5). Animals (X-1 and X-2), the two animals receiving the greatest total amount of radiation, had a slight degeneration of the cortical cells of the adrenals.

Eyes - Although almost all animals at one time or more during and following exposure had a severe muco-purulent discharge from the eyes there was no evidence found of any gross or microscopic change in the eye with the exception of (C-2) in which a slight swelling of the anterior capsule of the lens was noted. No evidence suggesting the development of lenticular cataracts was discovered.

Skin - There was no evidence of any burns of the skin of any portion of the body of any animal of the experiment.

Comments

The initial experiments to determine the heating rate of various concentrations of saline verified certain previous data which indicated an optimum frequency of about 300 Mc for isotonic saline. This lead directly to the conclusion that frequencies of this order of magnitude would also be expected to produce maximum heating rates in the living animal with isotonic fluids and especially the blood "pool". It was also interesting to note that the time required to heat to boiling one-hundred-eighty cubic centimeters (180 cc) of isotonic saline was only seventeen minutes, under the conditions of the experiment.

It was hoped that by placing the animals inside a waveguide and thereby making them part of the resonating system, that power level measurements could be made, which when compared with the power levels prior to their entry into the system, would give a resultant power absorption. It was soon discovered that the tuning mechanism of the antennae was not sufficiently critical to give more than an approximation. In addition, the rather erratic characteristics of the transmitter made accurate tuning quite difficult. This latter factor also made the accurate metering of the frequencies transmitted somewhat inaccurate although the error in frequencies is only of the order of magnitude of about plus or minus 5Mc. It is felt that a great deal of additional work might be done on this phase in order that a better understanding may be obtained of the absorption factors of electromagnetic radiation.

These experiments have indicated that a frequency of about 300 Mc will produce very rapid heating in the rabbit. This heating of the tissues resulted in pathological changes which, when severe enough, were sufficient to cause death. The type of death was characteristic of an acidosis with hyperpnea, tetany, convulsions and respiratory arrest. In those animals which died and also those which survived, even though some of them exhibited few signs other than hyperpnea and pyrexia, the pathological changes were quite uniform. The most striking features were:

(1) diffuse degeneration of the neurons of the cerebral cortex, the medulla, the basal ganglia, the pons, and

the cerebellum in some cases, (2) diffuse degeneration of the epithelial cells of the proximal and distal convuluted tubules of the kidney, and (3) a mild to moderate degeneration of the myocardial fibers. These findings seemed to be prominent and constant regardless of the period of recovery from the last exposure, appearing in those dying immediately, as well as those animals killed and autopsied as long as one-hundred-nine days after the last exposure. It was also noteworthy that in this latter instance the animal had received only a comparatively small quantity of radiation, as indicated by a rise in body temperature rectally of only 0.9°C after one hour and thirty minutes of exposure. The conditions of this exposure were not unlike the conditions of exposure which commonly occur in certain experimental electronic laboratories.

There seemed to be definite evidence of partial recovery from certain other pathological changes such as: (1) hemorrhage and edema of the larynx, trachea, and pulmonary parenchyma, (2) degeneration of the hepatic cells, (3) hyperemia of the spleen, and (4) hemorrhage and necrosis of the intestinal mucosa and stomach.

The complete absence of any ocular pathology was not anticipated. The reports of other investigators[117] indicated that power levels such as used in these experiments might produce lenticular opacities because the transmitter output was almost invariably in excess of 100 watts. Although it is recognized that the power density, according to the size of the waveguide, was only slightly in excess of 0.1 watt/cm^2, the heating efficiency of the system used was greater than when used in free space. In addition, any absorption of energy sufficient to cause a generalized hyperthermia in which the ocular structures are also in the electromagnetic field, might be expected to become heated at a faster rate and, consequently, to a greater extent because of the notoriously poor heat loss mechanisms of the eyeball itself. From a practical standpoint in the exposure of operating personnel, this may be of some significance. A reasonable conclusion seems to be, if one can interpolate from the rabbit, that the dangers of cerebral, renal, and myocardial damage are greater than that of ocular damage. The exception might be in those rare individuals who might be receiving direct and localized beams of radiation to the regions of the eye. Of course, such circumstances would also place cerebral tissues in some jeopardy.

There was no detectable difference in the effects produced by "pulsed" as compared to "continuous wave" radiations in these experiments. The average power output of the pulsed radiations was essentially of the same order of magnitude as the peak power output of the continuous wave radiations.

Conclusions

1. Experiments utilizing a radio frequency transmitter to expose rabbits (Flemish females) were conducted in order to study the effects of this radiation on the body temperature and the pathological effects of such radiation. The transmitter emitted a carrier wave of the order of 300 Mc which, in certain experiments, was modulated with a noise signal, which had a random

frequency up to about 5 Mc, and in other experiments the carrier wave was unmodulated. A small series of experiments was also conducted to study the rate of heating of various concentrations of saline.

2. The duration of exposure of the experiments on rabbits varied from seven (7) minutes to forty (40) minutes and resulted in varying degrees of hyperthermia in all cases and in nine (9) deaths. All animals exceeding a rectal temperature of 44.5°C at the termination of exposure succumbed. Two other deaths occurred after exposure, one in an animal whose rectal temperature reached a peak of 41.2°C, the other died 109 days after the last exposure, after reaching a peak post-exposure temperature of only 40.5°C.

3. The characteristic lesions found in both the animals which died spontaneously and those which were killed for post-mortem study, were various degenerative lesions of the brain, kidneys, heart, and to a somewhat lesser degree of the liver, gastro-intestinal tract, respiratory tract, and spleen. No significant evidence of damage to the ocular structures was noted.

4. The results of these experiments indicate that "whole body" irradiation by radiofrequency transmitters using frequencies of approximately 300 Mc may be expected to produce degenerative lesions of the central nervous system, kidneys, myocardium, liver, gastro-intestinal tract and respiratory system in about that order of decreasing severity, provided that power densities are of sufficient magnitude. The question of the accurate measurement of this critical power density is one which awaits further study and evaluation. It is hoped that this work will serve to stimulate further investigation along these or similar avenues.

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