PROCEEDINGS OF TRI-SERVICE CONFERENCE ON BIOLOGICAL HAZARDS OF MICROWAVE RADIATION

15 - 16 JULY [illegible]

Compiled and Edited by
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University of Virginia

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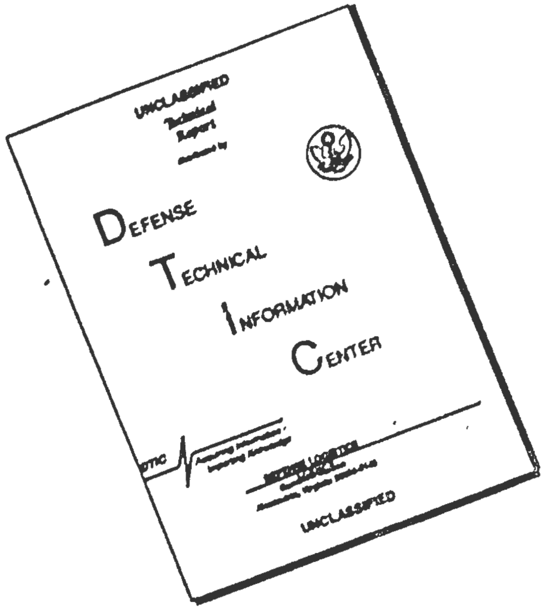

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PROCEEDINGS OF TRI-SERVICE CONFERENCE ON BIOLOGICAL HAZARDS OF MICROWAVE RADIATION, 15-16 JULY 1957

Compiled and Edited by
Evan G. Pattishall
University of Virginia

Sponsored by
Air Research and Development Command, Hdqs.

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The George Washington University
Washington, D. C.

PREFACE

Through a contract with The George Washington University, Air Research and Development Command Headquarters has been advised on the microwave radiation hazards and research needs by a group of outstanding scientists of various disciplines. This group held an initial meeting at Rome Air Development Center on October 31-November 1, 1956.

With the advent of the newly assumed Air Force responsibility for tri-service coordination, it became desirable to assemble the ARDC advisory panel, tri-service representatives, and various contractors working in the radiation hazard area to effect an understanding of activities and accomplishments to date.

The following series of papers represent the contributions of many leaders in the fields of biology, physics, and medicine. They were presented at a meeting of scientists interested in the biological effects of microwave radiation held at the Rome Air Development Center, 15-16 July 1957, and sponsored by Headquarters, Air Research and Development Command.

The papers which follow appear in most instances as they were presented at the conference, except that in many cases additional information was supplied in the form of references or supplementary materials.

The agenda for the conference followed essentially the same sequence as presented here with Dr. Al Hetherington orienting the group on the Air Force's new tri-service responsibility, followed by Major Dan Williams' summary of the School of Aviation Medicine's research program on the biomedical aspects of microwave radiation. Dr. Morris Handelsman then presented background data on the planned RADC program, and Dr. J. S. Burgess summarized the highpower facilities existing at RADC, and Col. George M. Knauf outlined his plans for a radiation hazard research program at Rome Air Development Center.

Dr. C. R. Larkin then presented a summary of radiation hazards to ordinance, and Dr. John L. Spencer talked on the exposure of Air Force personnel to ionizing radiation. Dr. Herman P. Schwan discussed the physiological basis of RF-Injury and Dr. Thomas S. Ely reported data on laboratory animals exposed to microwaves. Dr. Stephen J. Fricker then presented a summary on RF Measurements and the conference closed with a free discussion on related problems.

Attention is called to several important contributions included in the appendixes which are referred to at various places in the main body of the proceedings.

Special thanks are expressed to Col. Knauff, Mr. Tallman, and Mrs. Frank of RADC for their hospitality and skillful handling of arrangements for the conference.

It is hoped that the following presentations will be useful in summarizing the present knowledge on the biological hazards of microwave radiation and may be of value as source material for future researchers.

Evan G. Pattishall
Charlottesville, Virginia
September, 1957

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INTRODUCTION

by

Dr. Albert Hetherington
Human Factors Division
Air Force Research and Development Command
Baltimore, Maryland

This meeting of representatives of the three services and a number of their contractors, past and present, who have studied the biological effects of microwave radiation is the first major gathering which has been held to discuss programs and progress in the area since the Air Force was assigned tri-service coordinating responsibility.

Most of you will recall that this responsibility was exercised originally by the Navy, and then, when it was transferred at their request to the Air Force it was delegated by Headquarters, USAF, to the School of Aviation Medicine, Randolph Field. At this time the Navy had closed out its fine in-house research effort in microwave effects at the Naval Medical Research Institute; and the Air Research and Development Command had just been instructed by USAF Headquarters to transfer its radiation biology program from the Cambridge Research Center to the School. Hence, assignment of the tri-service coordinating responsibility to SAM, along with the research mission, was a logical step. They had essentially the only remaining in-service capability consisting of scientists working full-time in the field.

Now that the research mission in microwave bio-effects has been returned to ARDC the coordinating responsibility has come with it, and we in the Headquarters are finding, as the Navy people must have, that attempting to live up to it takes inordinate amounts of personal time.

We, also, are looking for someone to give the job away to, and we think out local hosts for today's meeting might be just the people who could give it a happy home.

Before I go further, I should probably define for those from outside the armed services what we mean by "tri-service coordinating responsibility." Doing so may prevent some misunderstanding of the phrase. It does not mean transferring all R&D work from the other services to the service with coordinating responsibility. Nor does it mean that the coordinating service directs or supplies guidance for the programs of the other services. The Navy, in particular, still has its own sizable contract research program in this bio-effects area. The Army, too, has its own interests and programs.

What the coordinating function entails is the assumption by one of the services -- in this case the Air Force -- of responsibility for providing the means whereby all three departments can stay well informed about all the programs going on in each department. This information transmission, or communication, activity is executed by holding conferences between project personnel, arranging symposia on the pattern of this one today, appointing technical discussion panels, supplying a meeting place and housekeeping arrangments when necessary, providing for the publication and distribution of technical papers not otherwise taken care of by the service R&D agencies, and similar services. Someone has to pick up the ball and carry it in these matters, and the Department of Defense realizes that something which is left to be everybody's responsibility usually turns out to be nobody's responsibility. So, in this case, by mutual agreement the Air Force was tagged.

It has therefore been a part of our obligation and our intention to hold periodic meetings to keep the other services informed as to our activities and to learn about theirs. Hence, when Captain Phoebus, of the ONR, suggested to USAF Headquarters people that he would like to see a tri-service meeting held, we readily agreed. We had been planning a contractor meeting for the immediate future, anyway, in order to complete the transfer from SAM to Rome of contracts being carried on under the project, and it was simple to expand the scope of the meeting to include a discussion of the status of the entire program and representation from the other services.

We will certainly plan to hold additional coordination meetings in the future as we or the other services determine that they are required. However, before this meeting is adjourned we would like to hear discussion of the possible need for another similar general status symposium sometime in the future, or perhaps for more limited symposia covering special topics within the microwave bio-effects area.

Some of you will probably be asking yourselves what the significance of all this movement and planning and discussion is. Is this just another phase, or are we serious about really studying the problem now? Do we intend to support the program? The answers to these questions are, Yes we are, and we do.

From its past history at least some of you will recall the shifting disciplinary emphasis this technical program has had in the service laboratories, and the various locations at which it has been carried out. It went from its Navy home to the Air Force, and from the Cambridge Research Center to the School of Aviation Medicine. Now we are transferring it to Rome Air Development Center.

The vicissitudes of the program have been caused, I believe, by the step-wise maturation of our understanding of the problem area. It received attention first from the biophysicists, who were perhaps best prepared to understand its possible ramifications. But then it came to be conceived of as a purely clinical medical program, rather like industrial toxicology, or a health physics program at an AEC installation.

However, the scope of the potential problem has gradually been revealed as being beyond the resources of any single discipline, and as being relevant largely as a function of the state of the art in equipment design. As in some of our other Human Factors areas, we have become convinced that the most valuable work can be done here only by a collaborative effort. The physical scientist designs the equipment which creates the radiation environment. The biologist then attempts to identify the physiological and pathological effects of the enviornment and to correlate the extent of these effects with the measured intensity of the environmental variable. At this point he must fall back on the physicist for instrumentation capable of analyzing and measuring the environment. Next the physicist and the biologist must collaborate with the chemist in the interpretation of effects at the molecular and cellular level. Finally, the work of all three produces information which most likely will have definite implications for the physicist and his design activities.

It is this growth in our general appreciation of the ramifications of the problem area which, I think, has at last led us to the logical decision which has now been made to concentrate the bio-effects program at Rome, where the radar equipment development is going on. Here the biological and physical scientists can work side by side in full knowledge of each others actions. The presently planned effort is small, compared to the effort going into equipment; but it will be allowed to grow as future developments indicate it may need to. We intend to support the bio-effects program with resources and manpower as required.

In the management of the program we intend to rely heavily upon the judgment and experience of an advisory panel of outstanding scientists of various disciplines with extensive personal backgrounds in the field. This group is under the chairmanship of Doctor David Cogan, of the Massachusetts Eye and Ear Infirmary. We also expect to make their assistance on technical matters available to RADC to the extent that this fits in with the Center's desires.

PRESENTATION I

A SUMMARY OF THE SAMUSAF PROGRAM FOR RESEARCH ON THE BIOMEDICAL ASPECTS OF MICROWAVE RADIATION

by

Daniel B. Williams, Major, USAF
Department of Radiobiology, SAM

Richard S. Fixott, Colonel, USAF (MC)
Chief, Clinical Sciences Division, SAM

INTRODUCTION

Effective 1 July 1957 the responsibility for research on the biomedical aspects of microwave radiation was assumed by the Air Research and Development Command. Coincident with this date the School of Aviation Medicine has terminated its program of 2-1/2 years of research in this problem area. The following is a review of the SAMUSAF program (1) during this period.

At the time the Air Force initiated research on microwave effects a review of existing information established the following conclusions: (a) Micorwave injury had been qualitatively demonstrated in animals, but had not been observed clinically in radar personnel, (b) Animal eyes, and particularly the testes, were especially vulnerable to the shorter wave-lengths, (c) Experimental injury appeared thermal in nature; i.e., temperatures induced in the affected regions were sufficiently high to account for injury on a thermal basis, and (d) No reliable information existed on the power densities of the modern radar beam and the parameters of injurious exposure were unknown.

Accordingly, the first two objectives of Air Force research were: (a) To characterize experimental injury in terms of the parameters of exposure responsible for its production, and (b) To identify hazardous regions of the radar beam. For obvious reasons ocular and testicular effects were selected as initial endpoints of concern--the latter has proved the most sensitive and may be the limiting factor in human exposure in the 1,000 to [illegible]00 megacycle/second range. As an interim safety measure, clinical surveillance programs were initiated on selected groups of radar personnel. Finally research contracts were neg[illegible] support of the overall program pending the development of [illegible] esearch facilities.

REVIEW

The major contributions during the first year of the SAMUSAF program were four publications which represented a culmination of inservice radiologic studies (2,3,4,5) initiated at the Air Force Cambridge Research Center and Rome Air Development Center, and completed at the School of Aviation Medicine, USAF. Collaborative efforts at Air Force Cambridge Research Center produced two publications on radiofrequency and microwave dosimetry (6,7). All of the studies were supported by the [illegible]metr[illegible] efforts of Rome Air Development Center. The results of this work furnished guide lines for establishing exposure limits at "S"-band radar and diathermy frequencies.

Based on these and subsequent data, Rome Air Force Depot of the Air Materiel Command published Urgent Action Tech Orders (8,9 which disseminated pertinent information to all major Commands. The latter AMC Tech Order (9) and a recent RADC Regulation (10) establishes a hazardous microwave radiation level of 10 milliwatts/cm^2 or greater, over the entire microwave spectrum. This value is consistent with the earlier recommendations of Schwan and Li (11), Ely and Goldman (12), and Williams (13) for "S"-band frequencies. Different limits eventually may prove desirable at other frequencies.

Briefly the early Air Force data (2,3,4,5) showed that experimental cataracts could be produced in rabbits by several minutes of exposure to power densities in the range of 500 to 600 milliwatts/cm². The threshold of experimental ocular injury for a single sustained exposure of 270 minutes was bracketed between 120 and 220 mw/cm². Temperatures significant in cataract production were bracketed between 49° and 53°C.* Of considerable interest was the observation that detectible testicular changes could be produced in the rat by 15 to 20 minutes of sustained exposure to 30 to 40 mw/cm².** The minimum testicular temperature associated with injury was between 38° and 40°C.*** It was concluded that the experimental ocular and testicular injury thresholds should be regarded as hazardous for man but that the risk of injury was minimal under current standard operational conditions. This conclusion was confirmed by the November 1956 report (15) of the ARDC MICROWAVE PANEL which observed that "there is no substantial evidence of injury having resulted from accidental exposure to RF radiation under either field or laboratory conditions."

During the second year the program was expanded along three phases: (a) Two ocular surveillance studies on electronics personnel at Rome Air Development Center (16,17), (b) Two studies on x-ray production by high voltage electronic power tubes (18,19), and (c) The negotiation of five

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*Measured in the vitrous at the posterior lens capsule. These limits recently have been rather conclusively refined to 49° to 50°C in the same region (14).

**These limits subsequently were pursued to lower levels by Ely and Goldman (12) who feel that 5 to 10 mw/cm² is the steady state dose rate limit for testicular exposure at "S"-band frequencies.

***38°C also was found critical in studies by Ely and Goldman (12) except in one case at 37°C.

research contracts on microwave radiation effects (20,21,22,23,24). Corollary efforts included procurement of equipment and development of an inhouse irradiation facility which will be discussed in a later section of this report.

OCULAR SURVEILLANCE

The ocular surveys were accomplished by Colonel Richard Fixott and Dr. Heinrich W. Rose of the Division of Clinical Medicine at the School of Aviation Medicine with the cooperation of the Commander, RADC, and the Surgeon, Griffiss Air Force Base. This work became the basis for what is now an inhouse task at RADC (25). Briefly, Dr. Fixott and Dr. Rose baselined 26 electronics personnel and 8 control subjects at RADC in addition to 17 personnel routinely associated with radar operation at Keesler Air Force Base. Subsequent examination of these personnel by Drs. Fixott and Rose has not revealed ocular variation which differs materially from those found in the approximately 100 control subjects who were examined at Randolph Air Force Base and vicinity.

X-RAY SURVEYS

The two x-ray surveys were conducted by Captain L. Logie, Lt. S. Sigoloff, Mr. H. Borella, and Mr. E. Richey from the Radiation Dosimetry Section, Department of Radiobiology, SAMUSAF, again with the cooperation of the Commander, RADC, and the Surgeon, Griffiss AFB. Dosimetry instrumentation employed for x-radiation measurement was comprised of quartz fiber types (26) and chemical dosimeters (27) which are not affected by the presence of rf-microwave energy. These studies gave for the first time an extensive series of reliable measurements which indicated the nature of the x-radiation problem at RADC and became the basis for RADC inhouse program in this problem area (25).

FISCAL CONSIDERATIONS

The five SAMUSAF contracts negotiated in the second year of the microwave effects program are valued at about $90M. About $20M of the funding was supplied out of the budget of the Department of Radiobiology, SAMUSAF, and was not therefore shown directly under microwave effects budgeting. It should be noted, however, that SAMUSAF, as Tri-Service Coordinator for research in this problem area, maintained surveillance of pertinent research of other agencies* conservatively estimated at about $50M, or a total of $150M, allowing $10M for SAMUSAF inhouse efforts at that time. This does not include the cost of the contract which RADC independently negotiated with the University of Buffalo nor does it include funds which RADC has committed in support of dosimetry studies (25). Thus, a conservative estimate of the overall Air Force-Navy program for FY 57 appears on the order of $250M.

Plans for FY 58 included: (a) the continuance of existing contracts, if warranted, at the $90M level, (b) the expansion of the SAMUSAF inhouse capability to about $30M, and (c) the expansion of contract research by an additional $100M to $150M. Accordingly, the total worth of the FY 58 Tri-Service Program was projected at nearly $400M. This figure assumes that the Navy committment would remain essentially the same and that the Army would not undertake active research sup[illegible]

Tentative expansion of SAMUSAF contract research included three proposals: one from the Armour Research Foundation (28), a second from the radar Laboratories at the University of Miami, Florida (29), and an expansion of Dr. C. Susskind's work at the University of California.

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*Navy and M.I.T.-Lincoln Laboratory Studies: Fricker et al at M.I.T.-Lincoln Laboratory, Lexington, Mass.; Ely and Goldman at NMRI, Bethesda, Md.; Nieset et al, ONR contract at Tulane Medical School, New Orleans, La.; and Richardson, ONR contract at St. Louis Medical School, St. Louis, Mo.

Early this year, when it became apparent that the overall program was to be returned to ARDC, SAMUSAF discontinued negotiations with these agencies and referred them instead to RADC. Finally this past week a fourth proposal from the Southwest Research Institute (30) was referred to Mr. Tallman's office at RADC. This latter proposal was based on suggestions contained in the November 1956 report of the ARDC MICROWAVE PANEL (15) relative to microwave spectroscopic techniques applied to the study of microwave effects.

Pending physical transfer of the microwave effects program to RADC, SAMUSAF has completed the dissolution of our inhouse irradiation facilities including two variable frequency transmitters at 200-2500 megacycles/second, two fixed frequency transmitters at 3000 and 10,000 mc/s together with allied equipment. This equipment is in the process of being shipped to RADC for disposition.

SAMUSAF INSERVICE RESEARCH FACILITIES

The SAMUSAF inhouse program* perhaps deserves some mention inasmuch as its discontinuance leaves some gaps in the overall program. The Department of Radiobiology, SAMUSAF, assumed the responsibility for establishing the microwave irradiation facilities capable of sampling the rf-microwave spectrum initially at 200 to 400 mc/s intervals. Exposure parameters included pulsed vs continuous radiation and thermal vs athermal effects. The initial facilities were to be made available on schedule to all departments within the School, 1 June 1957. In the interim, projects within the Department of Radiobiology which were underway, included:

7783-6 - Microwave Dosimetry (in support of inhouse effort).

7783-7 - Absorption Characteristics of Biologic Materiels.

7783-8 - Histopathologic Effects of Microwaves upon the Rat.

7783-9 - Effects of combined X-rays and Microwaves upon the Eyes of Rabbits. (later, the monkeys)

7783-10- Microwave Effects Upon Isolated Nerve and Muscle Tissue.

Projects under consideration from other departments included studies on:

a. Performance..............................(SAMPSYC)

b. Tissue cultures..........................(SAMICRO)

c. Enzymes..................................(SAMPATH)

d. Ocular effects...........................(SAMOPHT)

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*Supported by an array of disciplines: 3 opthalmologists, 1 pathologist, 2 microbiologists, 1 enzymologist, 1 electronics engineer, 1 radiobiologist, 1 psychologist, 1 theoretical and applied mathematician, supporting technicians and consultation services of appropriate personnel (Biometricians, etc.) in the Schoool together with the 5 SAMUSAF contract research groups.

SAMUSAF CONTRACT RESEARCH

One purpose of SAMUSAF representation at this conference is to facilitate an effective transfer of the five SAMUSAF contracts to the [illegible] of RADC. To this end the status of each of the five contracts is briefly [illegible] The [illegible] over-all program is apparent.

Each of the prime investigators of the five SAMUSAF Contractors [illegible] prominent in his field of specialization and all are authorities on micorwave radiation effects within their specialty area. Each of the contracts is designed to answer specific questions which had arisen as a result of earlier qualitative research. For example [illegible] of [illegible] State University of [illegible] demonstrated previously that 3 cm. an[illegible] 3 cm. radiation could injure the hollow viscera of small animals, but left unanswered the quantitative cause and effect relationship. His present research (20) is designed to evaluate and extend his earlier findings to a study of functional effects in larger animals; namely the dog, and of prime importance, to determine insofar as possible the actual dose and dose rates which are responsible for these effects. The latter information is an acute requirement for developing permissible or acceptable dose limits of microwave energy.

Dr. Hines has two exposure series well underway at an "S"-band frequency (31). One is based on a single exposure of 2½ to 3 hours duration--the other is comprised of repeated exposures, each of the same duration. The power density employed is on the order of 300-400 milliwatts/cm² of 12.3 cm. radiation. This is sufficient to maintain skin temperature between 43ᶜ to 45°C which is close to, but below the level required to produce burns. These exposures in the dog eventually produced temperatures typically of 41.3° in the liver, 41.5° in the stomach, 41.5° in the gallbladder, 42.2° in the intestine, and 43.6°C in the skin. The studies to date have failed to reveal any functional liver damage. The results are too few as yet to permit final conclusions to be drawn.

In his most recent formal report Dr. Hines notes that these exposures have not produced the dramatic results observed in smaller animals, rats, guinea pigs, hamsters, and rabbits. His tentative explanation of this difference is based on a comparison of the ration of exposed body area to total profile body surface. He concludes that an even lesser effect would be experienced by man in a similar exposure situation.

Dr. Schwan's work (21) at the University of Pennsylvania is designed to provide a wealth of fundamental information on the dielectric constants of tissues and their reflection, transmission, and absorption coefficients over the broad spectrum of 1 to 10,000 megacycles/second. Special facets of his study include (a) the specialized situation of head and brain irradiation using actual tissues and tissue stimulants, (b) the analysis of energy absorption by the eye with a forecase of frequencies most dangerous to the eye, and (c) studies of body penetration and heating using phantom models with a simulated circulation--all materials possessing the appropriate dielectric constants. The work stipulated in this contract is underway with respect to the skin, bone, and brain combinations. Additional equipment support is a requirement to accomplishing all of the objectives.

The contract at Ohio State University (22) with Dr. Justus Lehman was in effect only four months before Dr. Lehman transferred to the University of Washington where recently it has been reopened. This work is at 900 and 2400 megacycles/second and is the only current experiment in this problem area known to involve living human subjects. The study is designed with dual intent. Primarily, it is desired to gain an understanding of the temperature characteristics in tissue and the vascular response to man exposed to these microwave frequencies which are of interest from the diathermic perspective as well as of importance in terms of radar systems. The results of this study should also provide direct support for Dr. Schwan's research at the University of Pennsylvania which is concerned mainly with non-living tissues and phantom models.

Dr. Susskind's work (23) at the University of California is largely devoted to exploration for possible athermal effects and is concerned with (a) an investigation of the effects of the "X", "L", "Q", and "K"-bands at cellular level using micorscopic and radioisotopic techniques, and (b) a study of irradiation effects upon genetics and longevity in mice. An irradiation facility has been developed in the Antenna Laboratory, Department of Electrical Engineering, University of California, Berkeley, California (31). A resistance bridge for use with thermistor temperature measurements has been constructed and tested. A wooden frame and other auxiliary equipment suitable for supporting laboratory animals has been constructed. Pumping and circulating equipment has been designed for use with biological solutions in experiments in which the solution is to be circulated and cooled in an attempt to isolate the effects of heating during irradiation.

Some testing has been initiated to establish procedures to be used in a controlled experiment to measure the effects of sublethal irradiation doses on longevity, growth rate, and genetic changes in Swiss albino mice. The animals are to be subjected to essentially total-body irradiation.

Tests to establish methods of preparing samples of yeast and similar m[illegible] use in suspension or on slides have been initiated, and [illegible] alternatives are being investigated. One of the first problems is the development of a method that would permit the samples to be subjected to essentially equivalent doses of ordinary heat absorption. A technique using a special dye whose color depends on the maximum temperature reached during the experiment is being investigated as are several other methods. It is anticipated that work on several additional topics will be initiated during the next quarter, and that the procedures for the experiments on longevity and allied effects will be definitely established and the experimental series begun.

The work stipulated in the Tufts University contract (24) under Dr. Russell Carpenter was designed to provide experimental support for the clinical surveillance studies conducted by SAMUSAF ophthalmologic personnel at Rome Air Development Center and elsewhere.

The frequency of Dr. Carpenter's work (2450 mc/sec.) is representative of "S"-band frequencies which have long been employed in radar development at laboratories and in the field and is one at which many electronics personnel have long sustained numerous uncontrolled exposures. Through liaison between Dr. Carpenter and the personnel of the M.I.T.-Lincoln project there has been a mutually beneficial exchange of information on ocular studies at both facilities. The ocular studies of the M.I.T.-Lincoln project have been conducted at about 400 mc/sec, a range of direct interest to RADC and to industry.

A total of 62 rabbits have been exposed to date under the provisions of the Tufts' contract. Of these, data on 56 have been used to determine an empirical threshold for opacity or cataract production, resulting from a single acute exposure (14). Studies on cumulative exposures are underway. Some cataracts have been produced by repeated exposures to apparently sub-acute doses. The parameters of exposure, however, are so close to threshold that it seems premature to claim that cataracts have been produced as a truly cumulative effect. A temperature of 49-50°C at the posterior lens capsule has definitely been shown to be significant in lens injury so that it seems reasonably certain that we are dealing with a thermal effect. It has been previously demonstrated in cutaneous studies (32,33) that cellular death from hyperthermia and probably coagulation is encountered at 5-10 minutes of exposure to temperatures of 49-50°C.

SUMMARY

The progress of the Air Force-Navy program to date best seems summarized by recalling that only three years ago the sole data available on microwave tolerance was that an estimated 3000 milliwatts/cm² should be regarded as hazardous for personnel exposure. In the interim the limits of today have been scientifically refined to a level of 10 milliwatts/cm² for a significant portion of the microwave-rf spectrum. Current work will provide limits for other frequencies.

Recent research has given a rational perspective to the dramatic implications of earlier qualitative research which inadvertantly aroused undue concern in many areas. Current work should answer questions such as --Are there cumulative effects, and if so, under what conditions? Are there significant athermal effects related to pulse and/or pulse rate? What are the most susceptible organs and systems? Are there unknown beneficial effects? Answers to these questions, even if not complete, will at least indicate the extent

to which they should be pursued in the future program.

RECOMMENDATIONS FOR THE FUTURE PROGRAM

Administrative

1. Hold an Open Microwave Symposium at an early date and annually or as often as needed thereafter with representatives from industry as well as the Armed-Services.

2. Establish a distribution list for progress reports among the various research groups.

3. Establish a series of subcommittees on:

   a. Dosimetry requirements.

   b. Tolerance limits.

   c. Ocular surveillance.

   d. Shielding requirements and methods.

Research

1. Where existing contracts have established irradiation facilities, encourage expansion of the work to include other research specialties of biochemistry, pathology, performance, etc.

2. Follow through and exploit any potentially valuable effect revealed in current studies.

3. Conduct at least exploratory work on the effects of microwaves combined with x-rays. One may prove a valuable technique for the elaboration of the effects of the other.

4. Determine the power densities in the vicinities of radar transmitters in order to facilitate delineation of hazardous areas in the field.

5. Determine the significance of testicular effects and the

power-densities and frequencies at which these effects become important.

6. Determine ocular damage thresholds at 3 cm. and shorter wave-lengths, particularly cumulative effects.

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PRESENTATION II

FUTURE MICROWAVE RADIATION HAZARDS

by

Dr. Morris Handelsman, Associate Director, R&D, RADC

Purpose

The purpose of this talk is to furnish general background data and information on the planned RADC programs involving high microwave power so that estimates can be made of possible future electro-magnetic (designated as e.m. hereafter) radiation hazards.

Introduction

It would be desirable to present explicit quantitative data in terms of watts/sq.cm., frequencies, exposure times, etc. However the fact that some of this data is related to classified projects makes this impossible at the moment. It is therefore not possible to furnish a general audience with specific power levels, frequencies, antenna sizes, etc. Instead it will be necessary to present only generally-known future trends and to indicate possible ranges of values, which perhaps is just as valuable to you. Of course, specific information can be furnished to research workers who need it in connection with their work for us.

General Description of Systems

Both radar and communication systems will contain hazardous e.m. power densities. For the most part the radar systems are characterized by pulse operation and scanning antenna beams, while the communication systems are continuous wave in nature and usually have fixed antenna beams. However, this is not now, nor in the future will it be true for all systems. For example, certain radars may have antenna beams fixed in space and certain communication systems may have scanning beams. This is of obvious importance in estimating exposure times to radiation.

The general search radar scans through 360° in azimuth, rotating uniformly at 2-10 r.p.m. The azimuth beamwidth (angular spread between 3 db. points) may be on the order of 1° - 5° or so. The antenna is mounted on a tower from 25' - 100' high. The radiated antenna beam is usually tilted upwards slightly, so that radiation in the direction of the horizon is about 3 db. (50% reduction) down from that in the direction of the peak of the beam. However, this upward tilt is not always the case at each site. In addition, a "searchlight" mode (i.e., stationary or fixed antenna beam) may be employed at different times lasting for varying periods.

The typical nodding-type antenna on a radar height finder operates by first slewing around to a designated azimuth position, and then nods up and down in elevation from about -2° or -4° to some upper angle, usually more than +5° (horizon is 0°) to establish the elevation angle of a target. About 10-20 complete up-and-down nods per minute is typical. This type of radar is often used in a searchlight mode at any elevation and azimuth angle of interest.

Power Densities Sub-Divisions Within Typical Systems

There are several subdivisions within each system where significantly different e.m. levels exist. Consider a typical radar system as shown in Figure 1.

First we have a rather high power density in the transmission line, which presumably is closed and therefore not readily accessible.

Incidentally, power density in this talk is average watts per sq. cm. The power density in the line, for practical purposes is:

Equation (1) $$W = \frac{P}{A_t}$$

Where W - power density, average watts/sq. cm.
P - average power output of transmitter, in watts.
A_t - cross-section area of transmission line, in sq. cm.

Actually equation (1) is not exactly correct, as the power is not uniformly distributed over the area of the transmission line, but this should be sufficient as a working formula.

Next, the power is conveyed by the transmission line to an antenna feed, which in turn "feeds" the energy on to the antenna. The energy in transit from feed to antenna propagates through space, which is usually open or not enclosed, and therefore somewhat more accessible to personnel than the inside of the transmission line. In the aperture of the feed the power density is given, again approximately, by equation (1), except now the feed aperture area A_f is used in the equation. The feed aperture area A_f is usually larger than the transmission line cross-section A_t, so that the power density in the feed is less than in the line.

Finally, the e.m. energy is radiated into free space by the antenna so that the system can perform its function. Here we have "lost control" of the e.m. energy in the sense that it is now radiating into the outside world. Since the operational requirements of the system demand that this energy be radiated into the outside world, it is here that we may face our biggest problems in the control of possible hazards.

Now the manner in which the antenna radiates its energy is somewhat complicated and subject to many variations. For purposes of simplicity and convenient generalization, we may grossly depict this process as shown in Figure 2. The available power P furnished from the transmitter through the transmission line and then the antenna feed to the antenna itself, is radiated outwards from the antenna, in a direction normal to the antenna aperture in most cases (but with very important exceptions in other cases). In order to obtain useful beams with low side-lobes, the energy is "tapered" across the aperture. A taper decreases the energy (power) smoothly from the aperture center where it is a maximum to the aperture extremities, where it is on the order of 10 db (one-tenth) down from the maximum.

After the e.m. energy leaves the aperture, its variation or dependence upon distance from the antenna is indicated in Figure 2. At distances "close" to the antenna, designated as the Fresnel or near-field region, given <u>approximately</u> by equation (2) below, the power remains fairly constant with distance and collimated in a beam of about the same size as the projected area of the aperture.

Equation (2) $$R_{Fresnel} < \frac{1}{4} \frac{D^2}{\lambda}$$

Where: R - distance from antenna, ft.
D - antenna aperture dimension (See Fig. 1), ft.
λ - wavelength, ft.

As indicated in Figure 2, the energy is not uniform <u>across</u> this beam due to the taper previously described. The power densities at the beam center and beam edges are, respectively (to a stron approximation):

Equation (3) $$\left.\begin{array}{l} W_{beam\ center} \approx 3P/Aa \\ W_{beam\ edges} \approx P/3Aa \end{array}\right\} \text{inside Fresnel region}$$

Beyond the Fresnel region, the radiated beam begins to spread out until at far enough ranges, the power density is decreasing according to the well-known law of inverse square distance. The range beyond which this inverse square law variation begins is the far field or Fraunhofer region, given very approximately by:

Equation (4) $$R_{Fraunhofer} > \frac{D^2}{\lambda}$$

A region of transition between the Fresnel and Fraunhofer fields is shown in Figure 2, and denoted as a quasi-Fresnel or cross-over region. In the Fraunhofer region, the radiation is in a diverging beam shape, with maximum intensity at the beam center, and decreasing away from the beam center with angle. The larger the antenna, the narrower the lobe, or the higher the "concentration" of power. This "concentrating" action is shown by equation (5) below:

Equation (5) $$\Theta_{b.w.} \approx \frac{70\lambda}{D}$$

Where: $\Theta_{b.w.}$ - beamwidth, or angular spread in degrees between 3 db. points of the beam, i.e., points where the power is one-half that at the beam center.

Another way of expressing the concentrating action of an antenna is to talk about its "gain". A large antenna with a narrow beam thus has a large gain. In terms of this gain (a pure number which can always be furnished for each antenna), the power density at the beam center in the Fraunhofer region is:

Equation (6) $$W = \frac{PGa}{4\pi R^2}$$

Where: Ga - antenna gain

Actual Power Densities

Now that we have discussed in general terms, the types of systems and how to estimate approximate power densities, we can better appreciate actual quantitative data. Higher power systems may occupy frequency bands as low as 50 mc./s. or so for radars and 100 kc./s. for communication, up to about 20,000 mc./s. or more, to use round figures. Average power levels may vary from about 1-10 kilowatts or so at the upper frequencies to perhaps several hundred kilowatts toward the lower frequencies. A level of one megawatt average radiated power may be a distinct possibility.

Transmission line sizes may vary from about 6-8 inches diameter in the coaxial types and several sq. ft. (area) in waveguide types at the lower frequencies down to the standard waveguide sizes at the upper frequencies (e.g. area of 0.5 sq. in. for X-band). Power densities in the waveguide transmission lines may then be as much as 10^3 average watts/sq.cm., thereby exceeding some selected value such as 0.01 w/sq. cm. by a factor of something like 10^5 times.

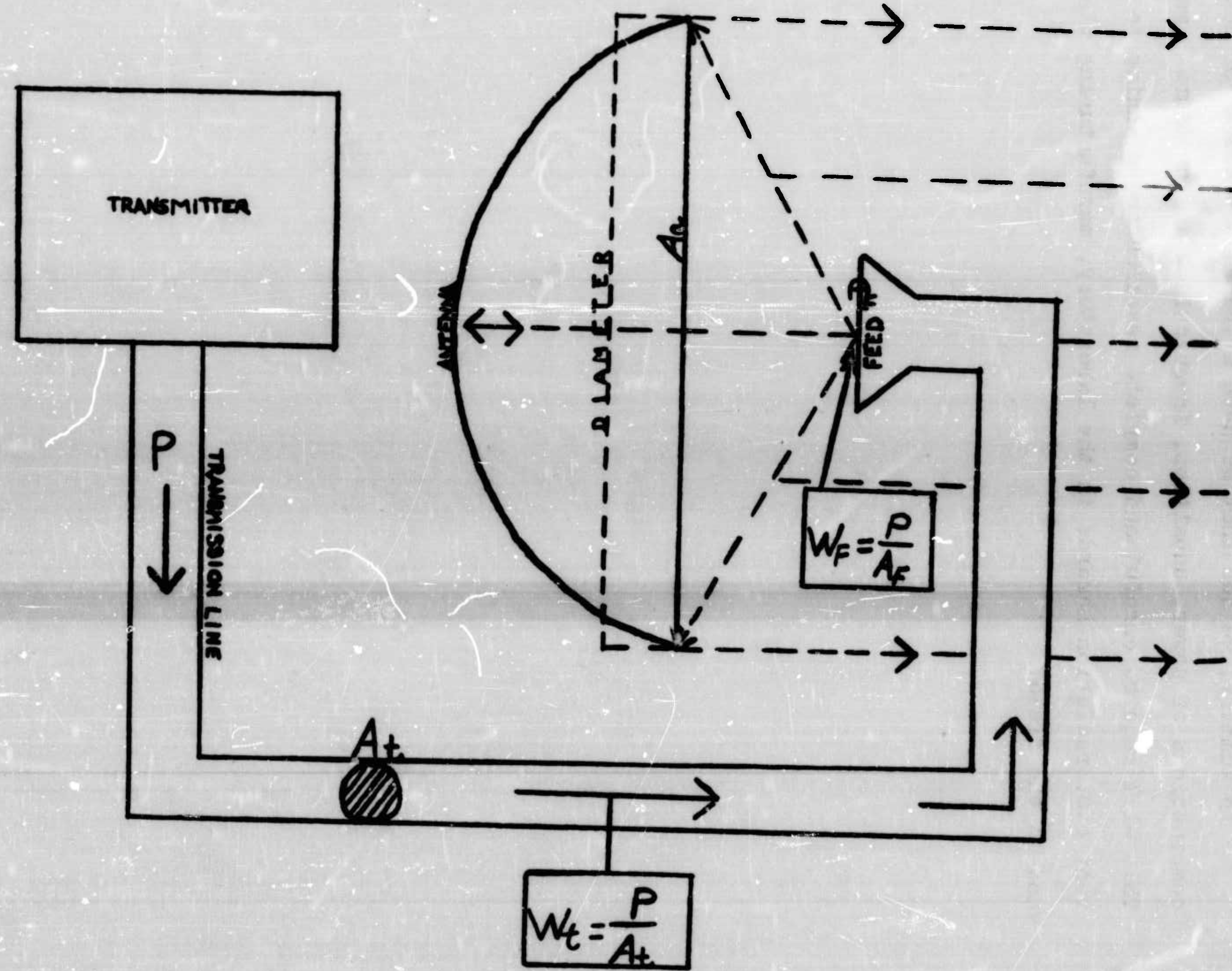
Turning to the antenna feeds, these vary in area from sq. inches at the higher frequencies to sq. ft. at the lower frequencies, with many variations from this norm due to specialized feeds for specific purposes. A person looking into or exposed to the radiation from these feeds, or standing inside one (quite possible!) will encounter average power densities less by a factor of 5 to 50 times that in the transmission lines, but still larger than 0.01 w./sq.cm. by a possible 10^4 times.

In considering the antenna radiation, we find that in the near (Fresnel) field, average power densities may be in the range of 0.0001 to 1.0 w./sq.cm., the latter value thereby exceeding 0.01 by a factor of some 100 times. The ranges (Fresnel) in which such power densities obtain may be on the order of magnitude of a mile. Beyond this distance, the previously described Fraunhofer decrease with distance as $1/R^2$ takes over, and equation (6) may be used for computation. It should be noted, since we are discussing antenna radiation at this point, that many sites may have several similar or different radiating systems "on the air" at the same time. In addition, as noted before, these radiation power densities exist over widely varying time periods depending upon particular systems usage.

Summary

In summary, we see that we have a tremendous number of possible combinations of power, densities, frequencies, and exposure times. This will require careful and complete research and planning to prevent e.m. radiation hazards in the laboratory, manufacturing plant, and in the field.

Figure 1


TRANSMITTER
P
TRANSMISSION LINE
ANTENNA
FEED
$W_F = \frac{P}{A_F}$
A_t
$W_t = \frac{P}{A_t}$

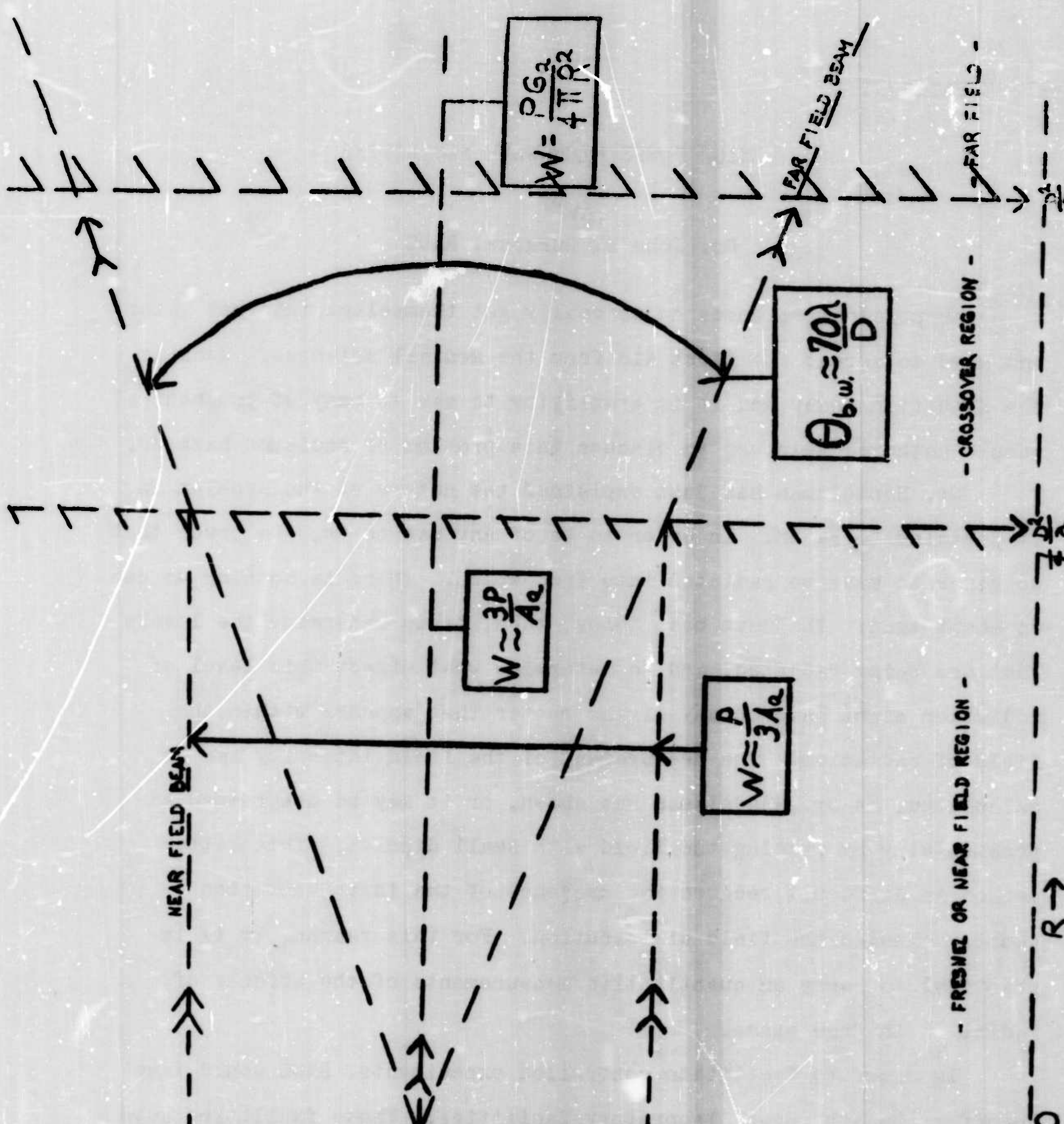

NEAR FIELD BEAM
FAR FIELD BEAM
FRESNEL OR NEAR FIELD REGION
CROSSOVER REGION
FAR FIELD
R=0
R→
$W \approx \frac{P}{3A_a}$
$W \approx \frac{3P}{A_a}$
$\Theta_{b.w.} \approx \frac{70\lambda}{D}$
$W = \frac{PG_2}{4\pi R^2}$
$\frac{D^2}{4\lambda}$
$\frac{D^2}{\lambda}$

Figure 2

PRESENTATION III

HIGH POWER MICROWAVE FACILITIES

by

Dr. John S. Burgess, RADC

The physical sciences occasionally get themselves into hot water and have to scream for first aid from the medical sciences. Such is the situation today and it is gratifying to see so many of you medical people gathered together to discuss this problem of radiation hazards.

Dr. Handelsman has just explained the nature of the problem as it pertains to radar. In order to be of any use to us, the power that we generate must be radiated into free space. There is nothing we can do about that. The next best thing, then, is to determine the levels that are being radiated, and to determine what effect this level of radiation might have on any living matter that appears within the field of radiation. The measurement of the field intensity can be calculated, as Dr. Handelsman has shown, or it may be determined experimentally by probing the field with small dipoles. This latter method is difficult because the presence of the instrumentation usually changes the field distribution. For this reason, it is impractical to carry on quantitative measurements of the effects of radiation in free space.

In order to facilitate controlled experiments, RADC would like to offer its high power laboratory facilities. These facilities have been set up for the purpose of making high power, high voltage tests on various electronic components developed by government and industrial laboratories. The power is confined to wave guide and cavity configurations so that the power density is quite accurately known. In order to give you an idea of the power levels available, I have listed them in the following table. (T indicates tunable)

Frequency	Tube	Peak Power	Average Power	Power Density
9200 mc	Magnetron	0.75 MW	0.75 KW	234 watts/cm^2
5400-5900	Klystron (T)	3.0 MW	3.0 KW	303 "
2700-2900	Magnetron	5.0 MW	4.5 KW	155 "
	Magnetron (T)	3.5 MW	3.5 KW	120 "
	Klystron (T)	5.0 MW	8.0 KW	276 "
1250-1350	Magnetron	9.0 MW	10.0 KW	86 "
	Klystron (T)	2.0 MW	6.0 KW	52 "
	Klystron (T)	10.0 MW	15.0 KW	129 "
400-450	Triode (T)	5.0 MW	300 KW	212 "

I would like to call your attention to the power density which is measured in watts/cm^2 which is to be compared to accepted level of 0.01 w/cm^2. The last triode listed will not be available for about eighteen months although I am sure we could make available quite high power levels at this frequency if it were required.

You will notice that some of the tubes listed are klystrons. These tubes operate at very high voltages, up to 250 KV, and as such, are very efficient X-ray generators. In fact, Col. Knauf has found out that we generate much higher intensity X-rays than he does at the hospital. Unfortunately, ours are not in a nicely controlled beam but spew out in all directions so that it is necessary to use a considerable amount of lead shielding around these tubes. X-ray tolerances have been fairly well established although it would be very helpful to us in preparing our equipment specifications if there were a single, accepted standard of X-ray tolerance.

There are several factors which are of concern to us in the operation of our high power laboratory. First is the X-ray problem which I have just discussed. Next, we know that there is a certain amount of leakage of our power through slots and cracks and joints, etc. We don't usually concern ourselves about these because we know they are quite low levels. However, it would be much safer if we had a direct reading meter that could tell us the power density at any point.

Occasionally, we have a test that requires that we radiate the power. For such a test we usually stick a horn out the window and point it up. These are usually short term tests that probably are more annoying because of interference than anything else.

It may be of some interest to you that we are presently carrying on toxicity tests on SF_6 in the laboratory. This material allows the use of high powers without pressurizing the wave guide. However, in the presence of a high voltage breakdown, the gas forms compounds that are toxic and corrosive. We are interested in measuring the toxicity so that we can take proper precautions in using this gas in our high power wave guides. If any of you are particularly interested in these tests, we would be glad to escort you to the laboratory where they are in progress.

I have attempted to give you a brief summary of the high power facilities which exist here at RADC. If these can be of service in measuring the biological effects of microwave radiation under controlled conditions, then we will see that they are made available to you.

PRESENTATION IV

PROGRAM FOR THE INVESTIGATION OF THE BIOLOGICAL EFFECTS OF ELECTROMAGNETIC RADIATION AT THE ROME AIR DEVELOPMENT CENTER

By

George M. Knauf, Colonel, USAF (MC)

You will notice on your program that I am scheduled at this point to discuss first the Rome Air Development Center bio-effects program and then to discuss the establishment of the Air Materiel Command permissible R/F exposure level. With your permission, I am not going to make any attempt to separate these two subjects but will interweave them as I go along since they do not lend themselves well to separate discussions. By way of orientation, let me first say that we here at Rome are concerned generally with 4 types of radiation as a result of our work in the development and maintenance of electronic gear. We are concerned with x-radiation, with microwave radiation, with infra red radiation and with ultra violet radiation. Let me dispose of the last two of these rather summarily by saying that we are in the process, at the present moment, of surveying the literature to determine what work has already been accomplished in these areas in an effort to clearly delineate any requirement which may exist for further research in these two areas. Should such a requirement be established, we propose to add this requirement to our present program for future accomplishment. Our principal concern here is with the first two types of radiation, x-radiation and microwave radiation. First, lets discuss our x-radiation problem. As you know, x-rays are produced at significant levels in the operation, in the main, of the magnetron and klystron. To some extent, this type of radiation results from the operation of many of our smaller power tubes as well. Without going into any detailed discussion of the sources of x-radiation, let me give you an idea of the magnitude of this problem by saying first that raw tube measurements have been made indicating an x-ray output of as high as 500 r/min from some of our larger high powered tubes. It should be born in mind that for the most part, these x-rays as measured have been well filtered by the shell of the tube and consist, for the most part, of only the high energy portion of the x-ray spectrum. The softer, less harmful, portions of the x-ray spectrum have been effectively removed by the filtration accomplished by the wall of the tube with the result that the radiation leaving the tube has been found to have an effective energy output considerably higher than the effective energy output of a broad spectrum x-ray tube. On the other hand, some of our lower powered tubes such as those used in certain pieces of laboratory test equipment have an x-ray output below the critical level of our film badges. Since in some instances, these tubes are found in bench equipment, we feel that we can not safely ignore this minimal x-ray output since many of our people are exposed to this radiation across the full 40 hour laboratory week. As you can imagine, this situation has given rise to some unique problems in the area of personnel monitoring. I do not propose to discuss that phase of our work in detail at this time since it will be discussed in considerable detail after lunch when we take up the Air Force exposure problem. Allow me to say in passing, that we here are not at all satisfied that we can continue to safely accept the published standard of 300 milliroentgens per week as the allowable exposure level for our people. We feel that in the face of the information being accumulated regarding the increased effective energy of this radiation that our permissible level should be lowered. This problem of personnel and area monitoring and the development of a dosimeter for this purpose will be discussed by Dr. Spencer this afternoon. We feel that in general, we are on top of this problem and are devoting a major portion of our time and effort to an assay of the biological effects of microwave radiation. As you well know, interest in the biological effects of radar energy is growing with enormous strides. This increased interest is found in our technical personnel as well as in the general public. Judging from the mail which crosses my desk, I would say that the public interest is rapidly moving from interest to concern. The reasons for this increased interest are to me interesting to consider. A few years ago, radar was something about which the public heard, but with which they had virtually no intimate personal contact. This is no longer true. As the average citizen rides along our highways, he is constantly reminded that his progress to his destination is being carefully observed by keeping him in a radar beam. He learns by means of the press that his favorite television program moves from point to point across the country by means of a microwave beam. He sees advertisements in store windows and in the press advising him that only this or that airline insure him a safe and smooth flight by means of radar carried in the aircraft in which he will ride. The juvenile mind is kept stimulated by the medium of comics which depict the remarkable results which may be obtained by the use of one or another of an array of ray guns. There is a movie going the rounds at the present time which incorporates a sequence in which an individual exposed to one of these very mysterious beams so shrinks in stature that he ultimately uses a straight pin to fight a duel with an insect. It is not remarkable to me that the public is concerned when with all of this background of orientation and indoctrination, they read a story in the press which characterizes this energy as "invisible death" and which further states that we are squirting this energy all over the place without any idea what we might be doing to people. Of recent date, I have been queried by responsible members of the medical profession who want to know whether any of our radar sets direct their beam toward the adjacent civilian community. These men are not alarmists, they are genuinely interested and I'm afraid that unless we take some positive corrective steps, this interest will grow into concern or even alarm. Among our technical personnel, we also have an increasing interest in the biological effects of this form of radiation. I am very happy indeed to say that their growing interest is based upon a much firmer foundation than that previously described, but nevertheless, there is evidence of an increasing interest and one which merits factual answers. The interest of our technical people is based upon the knowledge that we are rapidly expanding the frequency spectrum which we use and are now including in some of our higher powered equipments the lower frequencies which are capable of penetrating the human body more deeply than is true with the higher frequency, shorter wave lengths, commonly used up until the present time. They find little solace in the fact that there is no history of injury to personnel in the past since they know full well that the trend today is toward ever increasing power. They know that in the period immediately ahead of us we will see equipment which substitutes for the present 10 megawatt output, an output as high as 100 megawatts with average power reaching levels as high as 1,000 kilowatts. They tell me too that a technique has been developed overseas to couple power sources in such a way that the output rather than being additive becomes a geometric output thus making it possible, utilizing the equipment today in existence, to anticipate outputs as high as 1,000 megawatts. Our people recognize this situation and ask a very straight forward reasonable question, "What effect will this energy have on man?" At the present moment, we are without an answer to that question. It was as a result of our inability to provide adequate answers to the questions that are arising daily today that our program of biological effects was born. Let me say here, that in its inception here at Rome, our program concerned itself only with the effects of this energy on the total physical economy of man. It was our idea that should an effect be uncovered, we would set about to develop the protective devices or equipment necessary to safeguard the health and welfare of our people and leave the more basic study of the mechanism which resulted in this effect to those agencies charged with the responsibility for either basic or clinical research. We based much of our initial effort upon the fact that we feel ourselves as urgently in need of negative reports as we do of course of any positive evidence of an effect. This picture has changed somewhat in the last few weeks. We find ourselves now charged with the total program of the biological effects of microwave radiation and are at the moment in the process of realigning our sights in order to include this additional mission. We approached the problem generally in this way. We don't know where, if anywhere, in the overall microwave spectrum we might find the frequencies of greatest interest biologically. It is obviously impossible to explore all of the frequencies in the microwave spectrum. Limitation of funds and the limited number of investigators willing to devote their time to this problem made it immediately apparent that it would be necessary for us initially to sample the frequency spectrum at selected points. We elected to do this sampling at 200, 3,000, 10,000, 24,500 and 35,000 megacycles. This approach was discussed with members of the National Research Council, with the Surgeon General of the Air Force as well as with our own technical personnel. They all agreed that this was an intelligent approach and that should some one of these frequencies under study indicate a need for expansion of our investigation in some area of the spectrum, we could modify our initial program to concentrate our effort in that area. We outlined then the general scope of the information we were interested in obtaining and made this information available to a group of universities known to be interested in investigation of this sort. In general, our program embraced studies of the possible effects of microwave radiation upon living cells, tissues, and intact organisms. We asked that these experiments include both continuous wave and pulsed type energy. We expressed a desire to acquire information on the reflection, absorption, and transmission of this energy by different tissues using various combinations of power density and tissue. We asked that the problem of the effects of acute vs chronic exposure to this energy be thoroughly investigated. We asked that effort be directed to check for possible intracellular or intraneuclear damage which might result perhaps from molecular resonance, the interruption of enzymatic chains or the production of unusual free radicals. The response to our expression of interest has been most gratifying. As a result, today, the University of Buffalo is engaged in an investigation of 200 megacycle energy. The University of Miami is setting up to accomplish similar studies at 35,000 megacycles. We hope within the next couple of weeks to iron out certain administrative problems and get the University of Rochester under way on a program centered at 3,000 megacycles. One of the universities at present holding a contract with the School of Aviation Medicine of much more limited scope than we visualize has expressed an interest in expanding their investigation to embrace in general the type of investigation in which we have expressed an interest and I feel quite certain that when the transfer of this contract responsibility is accomplished from the School of Aviation Medicine to the Rome Air Development Center, we will be able to go ahead with this group and accomplish a more comprehensive study of the possible effects of exposure to 10,000 megacycle energy. Because 24,500 megacycles is the level at which water appears to demonstrate its maximum absorption characteristics, we have elected to include this frequency because of its possible physiological implications. We have received a proposal to conduct an investigation at that frequency which is not in all respects satisfactory. I have no doubt however that when time permits, it will be possible to interest some group in the investigation desired at this point in the frequency spectrum. It should be specified here too that we have indicated a desire that the investigating groups be made up of a well knit team composed of physicians, electronic engineers, physicists, biologists, and representatives of the other interested bio-sciences. I am of the opinion that such a combination of disciplines offers us the best possibility of attaining the desired result. As I said a few minutes ago, we are in the process at the moment of having the current contracts of the School of Aviation Medicine transferred to us for administration. I have to date not seen any of these contracts but have had an opportunity to read the statements of work made a part of each one of these contracts. Let me say now, that we here are impressed with those statements of work and do propose at the moment to continue all of them. I must ask to be excused from a more detailed discussion of this contractual effort since I have not had an opportunity to completely acquaint myself with that work. As soon as this transfer is accomplished and I have had an opportunity to study the work proposed in them, I plan to sit down with each one of the principle investigators in order that we may mutually exchange ideas. Insofar as the School of Aviation Medicine's program is concerned, I feel that this meeting is premature but wish to assure these investigators that at the earliest possible moment, I will sit down with them and go over their program. I do feel myself indeed fortunate in being given an opportunity to associate with such an outstanding group of investigators. So much for the Rome Air Development Center's program of investigation of the biological effects of microwave radiation. We recognize fully that our questions are not going to be answered overnight. We realize that we must patiently wait until our friends have provided us with answers to some of our questions. In the meantime, however, the problem is still with us. For the past couple of years, we have been bombarded with questions on the subject of the effect of this energy on the human being. In an effort to provide guidance for the field, we carefully surveyed the literature in existence in an effort to establish a safe exposure level to this form of energy. Many problems presented themselves. The frequency of the energy to which an individual was exposed, the nature of the exposure, whether it was acute or chronic, had to be considered as well as many like variables. We felt it impractical to attempt to establish an exposure level for various frequencies in the absence of factual data. We felt it much more practical to hit upon one safe exposure level and apply that to all frequencies. As a result of our study of the literature, we came to the conclusion that probably physiological damage did not result unless the power flux exceeded .2 watt/cm². However, there was an important element of uncertainty in our conclusions. As we reviewed the experiments as they were accomplished and the instrumentation that was used in the light of present "state of the art" know-how, we were forced to wonder whether we would not do better to look at this question of physiologic damage pessimistically. For this reason, we arbitrarily elected to consider that there was a possibility that some of the reported damage had resulted from power densities in the general neighborhood of .1 watt/cm². We recognized too that the expanded use of electronics in our everyday lives has resulted in adding to our environment minute amounts of microwave energy at many frequencies. Realizing how impractical it would be to measure the power density at each of these frequencies independently and believing that the sum of these assorted sources would not reach any great order of magnitude, we felt that they could best be provided for by applying to our estimated .1 watt/cm² a factor of safety of 10. We believe that this factor of safety of 10 provides us with sufficient latitude to embrace the sources I have just described and still provide us with a safety factor in keeping with good industrial medical practice. We propose this level as a common sense precautionary step in an effort to avoid harming our people while we wait for the output of our research program. I should say here too that when I described incidental sources of microwave energy I do not include other radar sets. This is not meant to be facetious. Within the last month, we have been queried by a facility operating two separate radar systems who asked the direct question, whether the measurement of 1 set was sufficient. They asked whether there is sufficient margin of safety in our proposed exposure level to take care of the second radar. The answer of course to this is obvious. We would have to know a great deal about the characteristics and location of the two pieces of equipment in order to answer a question such as this. Gentlemen, there is nothing about the establishment of a research program or the publication of precautionary instructions which in themselves legislate against the application of a little common sense. Our hand has been to some degree forced in the establishment of this safe exposure level of .01 watt/cm^2. Some months after we arrived at a decision to establish .01 watt/cm^2 as the Air Force safe exposure level, we received a report from a leading industrial laboratory in which it was proposed to establish the safe exposure at 1 milli-watt/cm^2. We did not agree with this level nor did we feel that we had sufficient data to contest this report. In the meantime, the same contractor in connection with another Air Force contract has written to say that in their opinion, .01 watt/cm^2 constitutes a completely safe exposure level for personnel. I do not know that the 1 milli-watt proposal has been rescinded but do believe the parent company has had a change of heart. More recently, another leader in the field of microwave research has sponsored a level of .1 of a milliwatt/cm^2 as being the safe exposure level for personnel. They further complicate the picture by saying that when the level exceeds .1 of a milliwatt and lie between .1 of a milliwatt and 1 milliwatt, personnel should be restricted from working in the area in excess of ½ hour in any 24 hour period. We can not find justification for this stand anywhere in the literature. In a recent conference with the engineer who wrote the report and the medical director of the company concerned, we got the impression that this level was sponsored in keeping with a company policy to take no chances. We are of the opinion that when they establish such a level they are indeed taking no chances. It should be said here too that we have not considered any point in time, reference to microwave exposure, as valid since we do not have at present any data which compares the effect of chronic vs acute exposure. For this reason, we have instructed the field to take precautions to avoid exposing people to ambient power levels in excess of .01 watt/cm^2 for any period of time. We have expressed an opinion that this level should be directed at average power density since all available data would indicate that the average or sustained power is the segment with which we are concerned. So much for our concern in a safe exposure level as regards microwave radiation. I have deliberately evaded the question of what we feel should be the safe exposure level of ionizing radiation as we encounter it in our laboratories. I feel myself completely without qualification to discuss this problem before an audience of this type. I do have, however, as my assistant, Dr. John Spencer, whose background of training and experience, eminently well qualifies him to discuss this subject with you. I have asked that he take my place on the program after lunch and discuss with you the Air Force exposure problem. He will limit himself pretty much to the field of ionizing radiation and I think that he will pass along to you some information which you will find to be exceedingly valuable. We know that this form of radiation can have serious effects upon the human mechanism. As contrasted with the knowledge concerning microwave radiation which conceiveably we might find to be harmless or even beneficial, I am of the opinion that when you have heard Dr. Spencer talk, you will, like myself, be convinced that we can no longer view the ionizing radiation output of electronic tubes with quite the complacency with which we have viewed it in the past.

(Refer to Appendix A - STATUS REPORT)

PRESENTATION V

HAZARDS OF ELECTROMAGNETIC RADIATION TO ORDNANCE

by

Dr. C. R. Larkin, Bureau of Ordnance

SUMMARY

With the increase in power of sources emitting electromagnetic radiations and a similar increase in the number of such sources installed on Naval vessels the several Bureaus of the Navy are becoming increasingly conscious of the possible hazards of the radiation to exposed personnel and to flammable or explosive stores. The efforts reported here have been directed particularly toward the latter items although some of the data which are being collected will be equally useful to the problem of personnel hazards.

I should like to outline briefly our method of approach to the problem of evaluating the hazards and I believe you will note a marked parallel with the method described earlier today in the summary of the School of Aviation Medicine program for biological hazards. I shall refer specifically to items of explosive ordnance and note that we are concerned chiefly with the sensitive electro-explosive device which initiates a chain of actions resulting in the ignition of the main high explosive charge. I shall call it a squib even though its technical designation may be different in varying circumstances. Omitting details, the plan of procedure is summarized in the following steps:

1. Determine the sensitivity of the various electro-explosive devices to ignition by RF power or energy.

2. Determine the pick-up and transmission charact ristic of weapons, i.e., the ability of the weapon as used or handled to absorb RF power in a known or measured field and to transmit it to its squibs.

3. Calculate or estimate the maximum permissable field exposure for a specified risk. This would be accomplished by a statistical treatment of the data obtained in (1) and (2).

4. Explore and measure the field intensity which may exist at critical locations aboard ships or other places where ordnance may be handled.

5. Make an estimate of the probability of accidental ignition. In cases where a high probability of ignition exists, a direct result may be obtained by exposing the weapon to field intensities known to exist and observing the "firing" of the squibs. If no squibs fire, however, very little information is obtained since, without measurement, there is no indication of how close the absorbed energy may be to the firing level.

The difficulties of obtaining sufficient data to supplement completely the plan described is great since the spread in the parameters to be measured is large and the number and range of the variables is likewise excessive. For example, the range of frequency encountered is such that it is unrealistic to obtain data at points other than those obtaining for the higher powered transmitters.

The determination of the field intensities existing on Naval vessels yields data which I believe to be applicable to all types of hazards aboard ship. A start has been made toward collecting this data and I shall present some of it today. Much of it has been obtained by the Bureau of Ships although the Bureau of Ordnance has sponsored some of the measurements. Those available to me at the moment have been obtained on the following ships: Canberra, Boston, Northampton, Mississippi, and Gyatt. In addition, measurements on certain transmitters at certain positions considered applicable to certain shipboard conditions have been made at the Naval Proving Ground, Dahlgren and the Naval Air Test Center, Patuxent. The chart (Table I) is a condensation of the results of the measurements with some pertinent data added.

Some discussion of the meaning of field strength or power density measurements is pertinent at this point. An electromagnetic field is characterized by four vectors: E, B, H and D. In free space the treatment is fairly simple, $D = \epsilon E$ and $B = \mu H$ where ϵ and μ are constants, and for a plane wave the electric and magnetic vectors are mutually perpendicular and in time phase . Further E is proportional to H and the power density is obtained by assuming the differential form of Poynting's Theorem:

$$\vec{E} \times \vec{H} \equiv \vec{S} = EH = \frac{E^2}{Z_0} = Z_0 H^2$$

where Z_0 is the "characteristic impedance" of space, defined by $E = Z_0 H$. Under these circumstances a probe properly designed to measure E or H will give us the power in the field. Unfortunately most of the cases with which we have to deal are not so simple. For example, the fields produced by an elementary oscillating charge (dipole) take the forms, in sperical coordinates:

$$E_r = \text{const} \times \left(\frac{1}{r^3} - \frac{i\beta}{r^2} \right) \cos\theta$$

$$E_\theta = \text{const} \times \left(\frac{1}{r^3} - \frac{i\beta}{r^2} - \frac{\beta^2}{r} \right) \sin\theta$$

$$H_\phi = \text{const} \times \left(- \frac{i}{r^2} - \frac{\beta}{r} \right) \sin\theta$$

in which we observe terms in time quadrature and in three powers of the inverse distance from the dipoles. Also there is present a longitudinal component (E_r). Only when the terms in $1/r^2$ and $1/r^3$ become negligible with respect to those in $1/r$ do we find the simple field structure outlined above. If we take arbitrarily the terms to be neglected as less than one percent of those retained, there results

$1/r$ terms only - Radiation or far field region - $r > 16\lambda$

$1/r^2$ and/or $1/r^3$ terms only - Induction field - $r < .0016\lambda$

All terms - Intermediate field - $.0016 < r < 16\lambda$

Where the radiator is itself a compound structure and where there are reflecting and diffracting objects in the neighborhood of the point of measurement, additional time phase changes will occur as well as a departure from the space quadrature relation between E and H. Under these conditions we must measure E, H, their relative time phase and their directional relation in order to determine the power density which now is taken as the real part of the Complex Poynting vector, $S^* = E \times H^*$. Expressed in other words the single probe may report accurately what power it can absorb in its particular orientation in the field and yet be in large error as to the actual field existing. By making cross check measurements and calculations, it is sometimes possible to gain insight into a limiting amount for the errors. Under these circumstances, however, we must be prepared to accept large errors in field intensity measurements taken in regions close to the radiators. Of course the weapon may be exposed under actual service conditions and the absorbed power measured but this reduces our investigations to an individual case basis and allows but little chance of prediction.

Trends for the future all indicate an appreciable increase in the power radiated by military transmitters. This will intensify the hazard problem. Our hope is that we may find means of reducing the danger more rapidly than the augmented power may tend to increase it.

TABLE I

Summary of Field Strength Measurements

Ship or Place	Position	Approx. Frequency (mc/sec)	Distance From Radiator	Field Strength (average) (volts/meter)	Power Density (average) watts/meter^2
USS CANBERRA	Launcher	6000	22 ft.	2.5	.017
USS GYATT	Launcher	220		1.2	.004
		1300		2.3	.014
USS Northampton	Gun Mount	10	30 ft.	> 2.0*	> .01
USS Boston	Gun Mount	16	130 ft.	> .1*	> $3x10^{-5}$
USS Mississippi	Gun Mount	2.6		.6 (H)** .002 (E)	
		6.5		50 (H)** $1x10^{-6}$ (E)	
		16.		1.8 (H)** .044 (E)	
		18.		.14 (H)** .2 (E)	
NPG (Dahlgren)	In front of transmitter	1300	12 ft.	64.	11.
	" " "	600	12 ft.	90.	21.
	"	220	6 ft.	106.	30.
	Gun Mount	8		.8 (H)/ 26 (E)	2.k
NATC (Patuxent)	In front of transmitter	3000	20 ft.	1010	2700

* Limit of measuring instrument
** H field report in volts/meter
/ H field in ampere turns/meter.

PRESENTATION VI

EXPOSURE OF AIR FORCE PERSONNEL TO IONIZING RADIATION PRODUCED BY RADIO FREQUENCY GENERATORS

by

John L. Spencer, Ph. D., and George M. Knauf, Colonel, USAF (MC)

SUMMARY

The development of high power, radio frequency equipment for detection, control, and communications, includes, almost inseparably, a concomitant problem in the production of spurious ionizing rays. Increases in r/f power, particularly as generated by diode tubes, are accompanied by serious aggravations of scattered ionizing energy, mostly in the form of x-rays and gamma rays. The magnitude of this electronic paradox was discussed in terms of biologic damage, sources of harmful radiation, and meaningful dosimetry.

The term ionizing radiations includes such diverse agents as photons, protons, electrons and neutrons, therefore, there is a need to determine their relative efficiencies in terms of induced biological change, and to relate these efficiencies to some physical characteristic which is common to all but which differs quantitatively for each. The differences in dosages necessary to produce similar events are considered characteristics of the radiations and indices of their RBE, that is, their relative biological effectiveness. The relative effectiveness of any radiation in a mammalian system is a complex function of the lineal energy transfer, depth-dose distribution, tissue dose distribution, etc. Predictions of biological effectiveness of radiations which obey only one of these variables are of questionable value and a prediction of RBE for man which is based

on results obtained from simple organisms is of limited value since such prophesies consider only the contribution of LET. Predictions of RBE for man would be better provided by values experimentally determined from other mammals. There is an urgent need for such data.

Four major events are experienced in the production of radiobiological damage. These are (1) absorption of radiant energy, (2) primary radio-chemical reaction, (3) chemical reactions chains, and (4) observable lesion. For the purposes of this discussion we are primarily interested in step number 4, that is, the observable lesions. Basically, there may be considered to be two kinds of lesions. The first is the somatic lesion,and this kind appears in the organism or system treated. It is not transmissible to subsequent generations. The second type of lesion is used in genetic analyses and is manifest as a genetic change or lethal effect. It is in fact, the cumulative damage to a system, an organism or population. In regard to somatic damage, it has long been known that ultra-violet and ionizing radiation, such as x-rays or gamma rays, have a carcinogenic action which may be produced by a single intense exposure or by chronic exposure to radiation. The source may be external or internal in the form of a radioactive isotope. Excessive dosage of x-rays or other ionizing radiation, injections of radioactive material, as well as accidental or occupational over-exposure, have led to this carcinogenic effect. Although these problems of protection from ionizing radiation have been with us since the injuries suffered by the pioneers in radiology were first noted, the focus of concern has of late shifted from obvious somatic injury to that of the much more subtle genetic injuries. In other words, man is becoming increasingly aware of the disastrous effects over-exposure to ionizing energies may have on subsequent generations. By genetic change we mean an alteration in inherited characteristics. These alterations or aberrations are usually referred to as mutations and they may be benign or malignant. Mutations are considered as representing a chemical change in the structure of the gene, the basic unit of inheritance. The exact nature of the change however, is unknown. Mutations may occur spontaneously, that is, in normal untreated individuals, or may be induced by special physical (ionizing radiation) or chemical (mustard gas) agents. Since we are considering ionizing radiation as produced by microwave generators, we should take cognizance of the fact that increased temperature, as induced by radio frequency energy, may play an important role in the background to susceptibility to ionizing radiation. Even before the discovery of the production of mutations by x-rays, Dr. H. J. Muller had shown that an increase in temperature of 10°C more than doubles mutation frequency. The relationship between mutation and the physical characteristics of the mutagenic agent, whether it be heat from radio frequency energy, ionizing radiation, or chemical substances, is obviously of great importance in an understanding of the mechanism of change.

Let us now consider some of the potential hazards from ionizing radiations as produced by our modern radio frequency power tubes. These tubes include magnetrons, klystrons, thyratrons, and a host of other types. For our purposes those electron devices that contain radioactive materials or gases also must be considered. With magnetrons and klystrons (diodes) there seems to be an almost linear relationship between applied plate voltage and the production of spurious x-rays.

There is also a rather direct relationship between the physical characteristics of the power tube and its ability to emit ionizing rays. Those tubes which produce longer radio frequency wavelengths are potentially more hazardous for x-rays than are those tubes which produce shorter r/f wavelengths. Data from 25 operating klystrons were presented. The most striking and significant values for x-radiation were obtained from the collector of the klystrons. At this location, an average of 800mr/hr was detected by the ionization chamber and an average of 830mr/hr noted on film. One klystron apparently leaked since 14½r/hr were registered by the chamber and 16r/hr by film. A lethal dose could be received from this tube by a person in less than a normal work week. It is significant, also, that the dosimeters detected an average of one mr/hr two feet from collector.

Investigations on the nature of x-ray production by hydrogen thyratrons revealed some alarming data. The x-ray emission from a thyratron operated with a constant plate voltage of 30kv and a prf of 100/sec. proved to be lees than 20 mr/hr. A change in the prf to 250/sec. (the other conditions remaining constant) resulted in a production of 360mr/hr. A further increase in the prf to 500/sec. caused a marked rise in x-radiation to 1,200mr/hr level to about 4,800mr/hr. As formidable as this quantity of ionization is, the significance of these preliminary tests is lost unless one realizes that these tubes were operating at considerably less than their capabilities. The plate voltage could be doubled and, in terms of effective time (prf x pulse length = 500 x 2μsec.), the power was "on", that is, pulsed only 1/1,000 of the time. At the present time one can only speculate on the potentially serious hazards from continuously operating (cw) tubes of this type. The quality of the x-radiation from these thyratrons was also determined. This attribute is one of the determinants of the relative biological effectiveness. Tubes operating with a plate voltage of 35kv, a prf of 500/sec. and a pulse length of 2μsec. yielded 1,500mr/hr through an air space of 12 inches and slightly over 200mr/hr through the same air space and .002" of lead.

Another source of potentially harmful ionizing radiation is the multitude of radioactive electron tubes that have come into common use. The Air Force inventories over 500 types of these tubes containing up to 10 microcuries of radioactive materials pertube. These materials include carbon 14 (C^{14}), cesium 137 (Ce^{137}), cobalt 60 (Co^{60}), nickel 63 (Ni^{63}), and radium 226 (Ra^{226}). Adequate disposal procedures for these tubes present several recognized problems; however, of more probable concern to personnel is the compounded, high levels of radiation that obtain in storage areas. Constant area and personnel dosimetry must be provided for at all levels. Disrespect for the damage that may result from mishandling a single tube leads to regretful hindsight.

The accurate detection and recording of ionizing radiation in an admixture with radio frequency energies involves problems of dosimetry generally not encountered prior to the advent of high powered r/f generators. Tests performed in which commercial area and personnel dosimeters were subjected to an r/f field demonstrated the marked influence this energy has on the ionization recorded. Relatively low power, as little as $1mw/cm^2$, caused the degradation or altering of the ionization measuring capabilities of many of the commonly employed types of personnel dosimeters and area survey meters.

The film type dosimeter, however, accurately records high levels of ionization even in very strong r/f fields. Absolute dosage determinations over large ranges of radiation flux are possible with photographic emulsions because the response to x- and gamma radiation is independent of flux for ratios in excess of 1:10,000. Dosimeters of this type have been developed which have an accuracy of better than ≰ 20 per cent when employed in an effective energy range of 100kev to 10Mev and a useful exposure range of 1r to 10,000r. As our concept of permissible dose has changed and degraded maximal exposure levels, our concern and need for the detection of fractional roentgens has increased. The film dosimeters in common usage by the Air Force have an accuracy, technique dependent, of about 10 per cent for a recording of 50mr or better x-radiation. A recording of 20mr of x-radiation may have an error of about 75 per cent, while a reading of 10mr may be as much as 100 per cent in error. Gamma radiation of less quantity can be detected with greater accuracy than can x-rays; 20mr would have an average error of about 20 per cent. The accuracies noted bear a somewhat direct relationship to the effective energies of the radiation. In general, the higher energies (100kev or greater) allow more reliable dosage interpretations. In fact, the threshold lies not much below 30kev.

For the most part, the ionization chambers, per se, of survey meters are insensitive to r/f but the associated circuitry is adversely affected. Very often an otherwise unsatisfactory instrument can give a reliable performance if properly shielded. These laboratories have found that best results with meters subject to r/f alteration are obtained when everything except the radiation window is fully shielded. The need for accurate, reliable dosimetry is all too apparent. Before any recording device can be relied on for meaningful detection of ionization in an r/f field it should be thoroughly investigated for possible induced discrepancies. Extreme care should be exercised in the selection and use of proper dosimeters. One may recognize potential harm as ionizing energy and its generators, yet the proof of its actuality rests with adequate dosimetry or biological damage. The choice should not have to be made.

The problem of health maintenance of Air Force personnel required to be in the vicinity of ionizing rays becomes one of prevention of exposure. A reduction in the number of intracellular radiations reduces the probability of harm. For the person who may be subjected to ionization produced by radio frequency equipment, there are three safeguards that must be considered. First, personnel should be made completely aware of the inverse square law, doubling the distance from the source decreases the radiation dose to ¼ of its initial value. Secondly, use shielding where necessary; 1/16" of lead is equivalent to 5 inches of concrete. Thirdly, personnel should be educated to rely on their monitoring system and dosimeters. Area and personnel dosimetry should be tailored to efficiently fit the particular requirements. Since the human system has no built in warning device for the reception of this type of energy, constant monitoring of equipment, people, and environment is necessary for the detection of potentially harmful ionization areas and the establishment of barriers.

The question as to what constitutes a harmful level is being answered with less assurance each day. The changing perspective, whereby damage that may be caused to unborn generations is under serious consideration, stems from a number of related events. Methods of protection have decreased the incidence of gross over-exposure and, yet, the increased production of x-radiation and radioactive emission from industrial, medical, and military use has resulted in a significant increase in the general level of radiation received by the world's population. This increase, coupled with the discovery that genetic change may be induced by ionizing radiation in amounts thought to be well below the so-called maximum tolerance dose, has cause a major realignment in scientific thought. Modern man, although he must be prepared to accept a limited degree of genetic damage for a small segment of the population, must guard against the overwhelming of his genic constitution by unwanted qualities. The level of acceptance, which is based on the concept of permissible dose, is involved with considerable philosophical thought and, for the military, not completely divorced from expediency. Until the time research affords evidence relative to man, exposure of personnel to ionizing radiation, regardless of source, should be as limited as practicality allows.

(Refer to Appendix B - Bibliography)

PRESENTATION VII

THE PHYSIOLOGICAL BASIS OF RF-INJURY

by

Dr. H. P. Schwan, University of Pennsylvania

ABSTRACT

Known and possible effects of UHF-radiation on biological material are summarized. The summary is not restricted to consideration of physiological aspects, but must include biophysical and other problems. A comprehensive survey of possible effects of radiation considers sequence of events which takes place: a) Interaction of radiation with the biological medium. This is covered from an energetic point of view completely by thermal considerations (heat development). b) Temperature rise results from heat development. Linear transient of temperature rise (short exposure) is predicted from distribution of heat sources. For longer exposure, heat flow characteristics must be taken into account. Substantial, but not sufficient work has been done which permits statements as to the time which separates linear transient and steady state. c) Nonlinear properties of thermal tissue characteristics are known from physiological studies. In particular, vasodilatation causes a nonlinearity of thermal conductance and thereby strongly affects temperature distribution. Pertinent results are summarized. They provide a qualitative idea as to the human body's response in case of partial body irradiation, but are insufficient to provide quantitative knowledge of response to either partial or total body irradiation.
d) Final temperature distribution affects corresponding variation of

permeable functions. Metabolic processes are accelerated at increased temperature. At temperatures above 45°C., processes of denaturation of biological macromolecules start. Again, little is known as to the biochemical mechanism and relevant time factors which are involved.

From the above sequence, it follows that the following changes are to be considered:

1. Response to moderate temperature elevation
2. Response to high temperature elevation
3. Nonthermal effects (such effects appear as "intermediaries" between wave and thermal energy)

A summary of all possible effects is given in each case. It results in the following classification of UHF-radiation effects:

A. Thermal effects (two subdivisions possible).

1. Volume heating	1. Reversible effects
2. Specific heating	2. Unreversible effects

This establishes altogether four classes of effects.

B. Nonthermal effects (athermal effects).

1. Known effects (Chain formation, reversible?)
2. Molecular "resonance" (?)

Molecular "disturbance" resulting from activation energies far below 1 electron volt (?)

Intermolecular response characteristics.

A summary of all these effects is given. In somewhat greater detail are discussed:

1. Volume heating.

This is determined by electrical characteristics. These data are largely, but not completely known and well understood in most cases. Muscle, fat, brain and eye tissues are discussed and their properties related to their electrolyte and solid component content. Electrolytes undergo maximum of absorption around 20,000 Mc., proteins display a range of relaxation times corresponding to frequencies between 100 and 1000 Mc. The significance of this knowledge is discussed.

Electrical data are converted into absorption coefficients, reflection coefficients, distribution of heat sources through skin, subcutaneous fat and muscle. The results are summarized and establish that radiation operating below 1000 Mc. penetrates deeply, radiation above 3000 Mc. is only a surface heating agent and radiation between 1000 and 3000 Mc. likely to be unpredictable with regard to its effective penetration and absorption characteristics. Consequences of this fact with regard to tolerance levels for total body irradiation are formulated, involving physiological considerations. Other consequences lead to an explanation why the 3000 Mc. is particularly dangerous for eye exposure, prediction that head exposure is more dangerous than total body irradiation and sensitivity of red bone marrow.

2. Specific heating effects.

The possibility to selectively heat small particles of distinguished dielectric properties is discussed in some detail. Conclusions: Selective heating of small particles (below 1 mm. diameter) is highly unlikely, but more possible with pulsed application of UHF, especially when the duration of the pulse is chosen small. Experimental and theoretical discussions of this problem are given, summarizing rather detailed knowledge of this segment of the total field.

3. Unreversible effects.

Destructive effects arise on a molecular level from the effects on macromolecular components, while the electrolytes are not sensitive. Irreversible effects, aside from thermal denaturation are not yet known. However, in principle at least various such mechanisms could exist and are summarized. Experimental and theoretical results, pertaining to chain formation of small particles under the influence of electrical fields, are relatively well understood and summarized. If this effect can be of significance on a macromolecular level is discussed and found unlikely, but not completely impossible.

Above summarized classification permits to order known results and reveals at the same time gaps in our knowledge. It is most expedient to use existing knowledge as a frame for further research. Furthermore, it sets into proper perspective theoretical, biophysical, physiological and experimental work.

(A complete manuscript will be published at a later time.)

PRESENTATION VIII

HEATING CHARACTERISTICS OF LABORATORY ANIMALS EXPOSED TO TEN-CENTIMETER MICROWAVES

by

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SUMMARY

Introduction

The increased use of microwave diathermy and of high field strength radar installations make it desirable to investigate some of the physiological effects of this form of energy. The primary effort of this study has been directed toward the delineation of the hazard of this form of energy and the structures most likely to be damaged appear to be the body as a whole, the lens of the eye and the testis.

The lens and the testis owe their special sensitivity to their physical location relative to the body surface, their poor ability to dissipate heat due to a poor or lacking vascularity, and in the case of the testis, high sensitivity to temperature increase. The body as a whole can tolerate only a moderate temperature increase, and has a limited ability to lose heat. The undesirable effect of excess temperature in the whole body, the eye, and the testis, is, respectively, heat disablement, lenticular opacity, and tubular injury.

As the investigation progressed, it became apparent that in all but rather restricted circumstances, the testis was the limiting factor with regard to hazard. Therefore the greatest effort was made on the study of this organ.

The 10 cm. wavelength under study is important because substantially

longer wavelengths penetrate deeper and are absorbed more diffusely by animal tissues, and are therefore less likely to produce small regions of differential heating, while energy of significantly shorter wavelength has very little penetration, and approaches the infrared in behavior.

It has been assumed that for a given experimental setup, the heating rate is proportional to the field intensity, and independent of time or temperature. In the case of the eye and the testis, the further assumption is made that the cooling rate is proportional to the temperature rise of the part, as opposed to other limited areas of the body where it is influenced by a thermally induced increase in blood flow. The whole body, which undergoes a considerably more complex physiological adjustment with increased temperature, follows a much more involved cooling patter, and in additinn experiences a change in metabolic heat contribution.

The cooling time constant was estimated usually by replotting the cooling curve on log-linear paper.

In order to maintain a prescribed temperature elevation of the structure under consideration under steady state conditions, the field intensity was controlled by an "on and off" cycling in response to the temperature of the subject. Since the temperature variation was very small with respect to the total temperature rise, the cycle time was much shorter than the time constant of cooling and thus the time average field could be used as the field intensity.

Ambient conditions, which form a direct and important factor in the application of the data to practical situations were controlled at dry bulb temperatures of approximately 24°C, radiant environment that of the dry bulb, relative humidity about 50% and air velocity essentially that due to convection only.

In the evaluation of critical temperature and critical field intensities, <u>any demonstrable damage</u> was used as the criterion, since if this resulted in an error of estimation, the error would be in the safe direction.

Most of the results have been presented in the form of a relationship between effect and field intensity, i.e. power per unit area.

Materials and Methods

Figure 1 is a block diagram of the major equipment used. The radar transmitter had a frequency of 2880 megacycles per second, or 10.4 centimeter wavelength, which is in the "S" band. Total power of the transmitter was attenuated by a directional coupler and a coaxial attenuator pad, and measured with a microwave wattmeter. The directional coupler led into a power divider which allowed the reduction of field strength to any degree, or the entire power could be shifted into the water load for calibration purposes. The horn radiated the microwave power into space providing a divergent field with vertical polarization.

Two synchronous timers were used to determine the time average of transmitter "on" time. One determined the total time during a specific exposure interval, and the other, which operated only with the microwave power, indicated the accumulated "on" time.

All of the microwave equipment, and the subject were contained in a commercial prefabricated double copper screen shielded room with a microwave absorber lining to reduce reflections.

The first phase of field calibration was the determination of microwave power output of the transmitter. This was accomplished by heating the water load by diverting all themicrowave power into it; and the temperature rise was recorded. Microwave power was then turned off and house current simultaneously supplied to the resistance heater. This was varied by an adjustable transformer until the temperature rise matched that produced by the microwaves, and the corresponding power was read from a wattmeter in the line.

Field strengths were determined by finding the field distribution for a known total radiated power, using a small receiving horn, attenuators, the microwave wattmeter, and a recorder. This system did not yield absolute values, but was satisfactory for relative measurements. Absolute field strengths were then calculated from the total microwave power, field distribution, and the average "on" time when cycling was used.

The animal exposures can be divided into two groups: large and restricted area exposures. For the "whole body" or profile area exposures, which represents the largest area likely to be exposed in the practical case, the subjects were: five rats having a weight in the range of 200-300 grams, 10 rabbits in the range of 3-4 kilograms, and 9 dogs in the range of 8-20 kilograms. For the restricted area, or localized exposures, radiation was limited as far as possible to the area of direct interest. The axis of the animal was oriented parallel to that of the beam and the appropriate end of the animal passed through a hole in a batt of microwave absorber to minimize general body heating. Eight rabbits and one dog were used in the eye heating experiments. Fifty dogs and three rabbits were used in the testis experiment.

Animal support structures were constructed of low heat loss materials of thin dimensions.

General anesthesia would have been useful during the whole body exposures to immobilize the animal, but of the several tried, all were found to cause a profound decrease in body temperature. The rats and rabbits were able to be exposed without medication but the dogs became quite active resulting in an additional metabolic heating. Premedication of the dogs with chlorpromazine, 6 mg/kg one hour before exposure was found to reduce activity without affecting the temperature significantly. For the localized exposures, general anesthesia could be used since body temperature was not of interest.

Temperatures were measured with thermocouples and thermistors. These were of two types, those mounted in needles for interstitial measurements, and those in flexible catheters for rectal measurement. Thermistors were used for the bulk of the work, since most of it consisted of single point recording on a continuous line recorder. Whole body temperature was measured rectally. For the eye exposures the thermistor needle was placed at the posterior pole of the lens, which site has been shown to be that of maximum temperature development and opacity production for the wavelength under consideration. Rabbits were used for all but one of the eye experiments due to the similarity of size and shape between the rabbit and human eye. Testicular work was carried out mainly on the dog, since this species had testes comparable in size and shape to the human organ. Testicular temperature was found to equalize throughout the organ with relative rapidity. It was also found, that with symmetrical orientation of the testes, temperature rise in each was essentially the same. This allowed temperature measurement in one and biopsy of the other which was undamaged by the termistor needle.

Results

Absorption "efficiency" of microwave energy was found not to be affected significantly by the presence of hair on the animals. The mean absorption "efficiencies" were calculated for the three species.

The steady state values of field intensity required to maintain a given body temperature for whole body exposures of rats, rabbits, and dogs were found.

Most animals of all three species survived a maximum temperature of 42°C, which was generally for less than one hour. Roughly half survived 43°C maximum, while 44°C proved uniformly fatal. Usually if the animal did not die during or within a very few minutes of exposure, survival was the rule.

Steady state field intensities for the eye exposures were found to be in the same ratio as the whole body figures. Cooling time constants for the eyes were all within the range of 100 to 180 seconds.

Steady state field intensities were obtained for the dog testis. In addition, an attempt was made to evaluate the effect on temperature of clothing and sweating. As would be expected, clothing decreased the field intensity required to maintain 38°C and "sweating" (drops of warmed water applied to the scrotum) increased it. When clothing and sweating were combined the results were similar to those when neither was used.

Discussion

The results of whole body exposures clearly show the failure of cooling mechansims at the higher temperatures. Cooling appears to reach a maximum limit and then fails, probably due to central failure of respiration.

As a preview to a proposed series of human whole body exposures, two such exposures were made. Due to the size of the human body, the field intensity was much lower at the periphery than at the center. Exposures were frontal, the first being at an ambient temperature of 24°C. and the second at 25°C. During both exposures the rectal temperature dropped slightly, showing the subject to be in good thermal control with mild sweating and without rise in core temperature.

In order to formulate an approximate human whole body hazard, the maximum heat dissipation ability must be known. This depends on many factors: air speed, temperature, humidity, metabolic rate, clothing, beam geometry and time.

A preliminary evaluation of the relative sensitivities of the three structures in the human has been made using experimental animal data. These are listed in Table 1.

TABLE 1

Structure	Initial Temp.(°C)	Maximum Temp.(°C)	Temp. Rise(°C)	Steady State Field (mw/cm^2)	Cooling time constant (sec.)
Whole body	37.0	39.0	2.0	100	(50 joules/cm^2)
Eye	37.0	45.0	8.0	155	100
Testis	35.6	37.0	1.4	5	250

Because cooling rate is a complex function in the human whole body, the thermal mass of the body in terms of profile intake intensity has been used.

Whole body, eye and testis thresholds for different field intensities were determined but depend on many assumptions and are only approximations. However, from the, it appears that the eye is more sensitive than the whole body for a short exposure, because of its smaller thermal mass. At longer times the whole body appears more sensitive than the eye, principally because of its lower critical temperature. It also appears that the testis is considerably more sensitive than either of the other structures.

A review of the literature was made toward finding the "normal" human testicular temperature and the threshold hazardous human testicular temperature. From this review it would appear that testicular temperature varies considerably from individual to individual and in the same individual from time to time, depending on different environmental factors.

The evaluation of a temperature threshold for testicular damage is a rather difficult problem. It is undoubtedly a function of exposure time, and probably also of age. It appears after a further review of the literature that normal body core temperature is damaging to the testis of many species although a well defined time factor is not known for man. Threshold temperatures suggested from the above review are: 37°C for five days, 37°C for one hour, and 38.2°C for one minute.

An additional factor in the evaluation of hazard is repetitive exposure. Irregular exposures would have to be evaluated on an individual basis. Regular exposures are found in three main practical situations: individual pulses of pulsed radar, scanning antennae, and work schedules such as a 4-hour watch, or and 8-hour shift. The principal reference in evaluating these repeated exposures is the time constant of the structure involved.

Although the criterion of hazard used in this study has been the least demonstrable damage, other factors should be considered in the overall viewpoint. The minimal testicular damage is almost certainly completely reversible. Even considerably more severe testicular insult will probably be reversible, with the only finding being a temporary sterility. An even greater injury can result in permanent sterility.

In the case of the eye, a small asymptomatic lens opacity would be of more concern than transient testicular damage. A disabling cataract would require only a moderately greater exposure, and would be considered a serious event.

From the whole body standpoint, minimum damage from generalized hyperthermia is difficult to evaluate. However, the large exposure resulting in death represents the ultimate effect.

Summary

Experimental animals were exposed to 10 cm. microwave fields and an evaluation was made of the heating effects. Cooling data enabled the formulation of curves of the time and field intensity required to achieve a given temperature. Of the three main sensitive structures, the whole body, the eye, and the testis, the last was found to be much more sensitive than the other two. Heating rate was found to be roughly proportional to field intensity, and in the case of the eye and the testis, cooling rate was essentially proportional to the temperature elevation of the part. The whole body cooling rate is a complex function only partly dependent on the temperature elevation. Threshold damage temperatures were taken from the literature and in the case of the testis, also from a histological evaluation. The heating, cooling, and threshold temperature data were put into a somewhat general form, which may be useful in the estimation of hazards to humans.

The formal report of this research (NMRI Project NM 001 056.13.02) included the following:

APPENDIX A

Appendix A consists of some mathematical considerations of the above study.

APPENDIX B

Early lesions in Dog Testes Due to Microwaves

INTRODUCTION

Appendix B consists of a report on microscopic studies conducted on 14 dogs following exposure confined to the gonadal region. Normal dog testicular temperatures ranged from 30.30°C to 36.25°C. Testicular temperatures in the treated animals varied from 36° to 44°C and were maintained in all but one case for 60 minutes.

MATERIALS AND METHODS

Most of the dog testicles were removed surgically on the fourth day after exposure, and rest on the third or fifth day. Two controls and one section from a testicle in which a temperature of 44°C was maintained for 60 minutes were first studied microscopically. Then the testicles from 11 dogs exposed to microwaves confined to the gonadal region were studied and an attempt was made to assess the degree of injury in terms of 1, 2, and 3 plus.

RESULTS

The upper limit of exposure accompanied by a 1 plus reaction was approximately 41°C for 60 minutes. No clearcut relationship between the [illegible] plus lesion and temperature and duration was established in [illegible] limited number of cases studied. The 3 plus reaction occurred in [illegible] testes exposed to 41°-44° C for 60 minutes.

In all cases the most severely involved areas were immediately adjacent to the capsule, the more central areas were either less severely or not at all damaged.

SUMMARY

Testicular reactions to heat injury from a radar source appear to be basically the same as those due to hyperthermia associated with other conditions and many other causes. Even in the most severely exposed testicle in this study, it is unlikely that the damage is of a permanent nature. Many of the tubules remained undamaged while many more were only slightly injured. A complete evaluation of a possible decrease in fertility was not undertaken in this study.

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REMARKS AT MICROWAVE CONFERENCE

by

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Office of Naval Research

The Navy program for research on the biological effects of microwaves contains four projects, three of which are continuing and one just now completed. The program indicates that I will review them, but since all of the investigators are present and are prepared to present their problems, I shall turn this portion of the program over to them. Dr. Schwan, from the University of Pennsylvania, who is principal investigator on one of our studies, reviewed his work during the morning session. The other two continuing tasks will be presented by Mr. Rene Baus, from Tulane University, and Dr. Alfred Richardson, from St. Louis University. Dr. Thomas Ely has just completed an in-the-house study at the Naval Medical Research Institute, Bethesda, Maryland, and will present his findings. I will now turn the floor over to Mr. Bauss.

Editor's Note: At the time of this printing Mr. Bauss' comments had not been received, however, these will be mimeographed and distributed when they arrive.

PRESENTATION IX

BIOLOGICALLY MEANINGFUL UNITS OF RF MEASUREMENT AND DOSIMETRY DEVELOPMENT

by

Dr. Stephen J. Fricker, Lincoln Laboratories

SUMMARY

1. <u>In High Level Fields</u> (of the order of .01 w/cm^2 or more)

   a. Basically make use of power measuring equipment rather than field strength equipment. This should have the general form of

      (1) Matched antenna with known gain at the specific frequency.

      (2) A coupling unit, to connect the antenna to the matched bolometer load.

      (3) A calibrated power measuring device, such as a bolometer bridge.

   b. Be careful of the geometry of the situation, i.e. attention must be paid to polarization and reflection effects.

   c. Check to make certain that the indicated power reading on the is all due to energy absorbed by the antenna (e.g. put a matched shielded termination in place of the antenna, leaving the rest of the physical configuration the same).

2. <u>In Low Level Fields</u>

   For example, where the main power source has been replaced with a low level source of known power. The final power density values may then be increased by the ratio of the powers.

   a. Use standard field strength measuring equipment, whose calibration has been checked.

      (1) As in 1(b)

      (2) As in 1 (c)

3. The method in 2 above allows the use of standard electronic equipment under conditions in which it probably will function correctly. It is possible to use well shielded electronic equipment, with attenuators, under high level field conditions, as in 1 above, but in general great care has to be exercised to obtain a meaningful measurement. Unfortunately, field values often may fall in the region between (1) and (2), where direct power measurements are difficult, and yet electronic equipment may be jammed. The usual remedy is to try to improve the shielding of the equipment.

4. Where possible, some thought might be given to using totally enclosed systems, in which one can keep a power balance to within 10% without undue difficulty. This obviously has more application to experimental irradiation systems than to monitoring of operational equipment. If an enclosed system is used, the main points to watch are:

   a. Matching of components (to insure power flow in the desired direction).

   b. Calibration of couplers, attenuators, and loads.

   c. Use of dummy loads absorbing measured (calorimetric) amounts of power.

   d. Care in the use of field measuring equipment, such as voltmeters, as power values derived from their readings are sensitive to quite small standing wave ratios.

(Additional data in support of this presentation see Appendix C)

PRESENTATION X

MICROWAVE EXPOSURE DISCUSSION

Moderated by

Dr. Stephen J. Fricker

A. OTHER RELATED PROBLEMS:

Dr. Fricker stated that he had been examining slides made from rabbit tissues exposed to microwave energy. The pathology of these rabbits was covered in a report prepared by Dr. Curtis of Harvard University. This report was concerned primarily with damage to the testes and eyes. The testes of 61 rabbits were examined and no differences were found between the exposed and controlled groups that could be attributed to microwave energy. These findings were substantiated in a subsequent investigation also reported by Curtis. Examination of the testes of the controlled animals revealed that four had normal testes, three abnormal, and one was inconclusive. For the nine exposed rabbits, five were abnormal, three were normal, and one proved to be a female. Dr. Fricker also mentioned the work of Dr. Ely who exposed dog testes to microwave energy. Although Dr. Ely noted a number of changes, these abnormalities also occurred in controlled groups. Of particular significance was the absence of active sperm from animals in both groups. This lack of active sperm may be due to immaturity. In some animals a tremendous amount of mitotic activity was observed even though they suffered a violent death. It was Dr. Fricker's opinion that their exposure to radar (468 mcs radiation) does not produce significant changes that can be identified as microwave induced aberrations. The changes seen are those usually noted as being induced by thermal conditions. It was Dr. Fricker's opinion that no significant changes occurred in the testes of the rabbits at the microwave intensities used. He added that these intensities were sub-lethal and would have resulted in the death of many of the rabbits if they were exposed for a longer period of time.

DR. LEO SILVERMAN, Harvard University School of Public Health:

"In the case of these irradiated rabbits, I would image that the profile is extremely important."

DR. FRICKER:

Dr. Fricker agreed that the profile was important but that he was not concerned with it for this particular experiment. Arrangements had been made so that the rear of the animal would get the major dose of the radiation for these testicular investigations.

DR. HARTMAN, Office of the Surgeon General, USAF:

Dr. Hartman discussed changes or damage to the testes in terms of their pathology. He stated that the changes Dr. Richardson had noted earlier in the meeting were real and definite. However, the cause of the change is an open question. Dr. Hartman indicated that in his experience with both animals and humans, the changes produced were very real physiologically and pathologically. There seems to be some anoxia in response to temperatures of 7-8° F above normal. Exposures to a hyperthermal temperature of 7-8° F for three to five hours resulted in very considerable histotoxic anoxia and the autopsies revealed hemorrhage of the brain. Dr. Hartman said the changes he had observed with abnormal temperatures, that is abnormally high terperatures, were the same that had been observed and reported by Dr. Richardson as occurring within 24 hours after exposure. He also noted that the results or the outcome from exposures to high temperatures could be regulated by the type of sedative. Heavy sedation by barbituates or sodium amytal frequently left the patient in a state where high terperature would cause greater damage. Dr. Hartman cautioned everyone to avoid heavy sedatives, particularly on extremely hot days. Dr. Hartman noted that Dr. Richardson found the changes in the blood but so far as therapy for heat is concerned the administration of water alleviated the situation in terms of patient comfort. Under the proper conditions temperature can be carried somewhat higher for a fairly long period of time. Dr. Hartman said that he had been associated with work where they demonstrated very significant changes in the liver, lung, and brain, even though not very much hemorrhage had occurred in the latter organ. He also noted that from what he had seen of Dr. Richardson's photographs, the effects of microwaves on organs and the effects of high heat on these same organs were comparable. Dr. Hartman thought that the application of microwave energy might not contribute directly to anoxia or to directly effect the enzymes. It occurred to Dr. Hartman from discussions at these meetings that the problem can't be settled until we reduce the number of variables. He believed they could be reduced substantially; he thought eventually the research would get down to the organic and cellular level. Most workers, thought Dr. Hartman, agree that temperatures are not necessarily the prime factor in a number of the conditions which have been produced, but most of these shown in these meetings are the result of excessive heat.

DR. GARDNER:

Dr. Gardner discussed shock and burns from microwave energy and suggested that there were some 17 variables in the problem. He agreed with Dr. Hartman and stated that these microwave problems are not going to be settled until the number of variables can be reduced to a working few.

DR. FRICKER:

Dr. Fricker noted that the mechanics involved in the reduction of the number of variables were formidable. He, too, agreed with the two previous speakers that the variables could not be forgotten and that we must continue to look for ways of reducing their number. We must find people who are willing and able to work in this field and to work precisely. We must find people who can combine the dynamics of biology with the preciseness of measurement.

DR. BAUSS:

Dr. Bauss discussed investigations where his group employed power densities of from .02 w/Cm^2 up to .2 w/Cm^2 on various animals. He stated that there were no changes statistic wise and that Dr. Richardson under a different set of conditions had found approximately the same thing.

DR. FRICKER:

Dr. Fricker asked Dr. Bauss if all the experiments were performed with pulsed microwaves. Dr. Bauss said that they were. Dr. Fricker noted that this probably changed the picture somewhat. Perhaps, noted Dr. Fricker, the major difference is a question of the high peak powers during the pulse. Unfortunately, the results failed to agree.

DR. BAUSS:

Dr. Bauss again noted that they had found no significant changes statistically.

DR. RICHARDSON:

Dr. Richardson said that other factors ought to be kept in mind, for instance the wave length. He noted that in April and May of 1949 they had run a series of animals searching for cataract production by microwaves. His group found that no cataracts at all were produced by 75 centimeter radar.

DR. SILVERMAN:

Dr. Silverman discussed why a 75 centimeter device is far safer than one having a shorter wavelength. He noted that although no damage was produced in the eye by 75 centimeter microwave power, cataract was produced with the much shorter wavelength.

DR. ELY:

Dr. Ely noted that his group did not use 75 centimeter microwave power but that he was surprised that this 75 centimeter wavelength did not produce cataracts.

DR. RICHARDSON:

Dr. Richardson replied that it (75 centimeter) was a relatively safe wavelength, biologically.

DR. FRICKER:

Dr. Fricker mentioned Dr. Carpenter of Tufts and his experimental work with animals in which he showed that a 10° C rise in temperature of the eye produced cataracts. However, this severe rise in temperature, if given as a whole body dose, resulted in severally heating the animals and they died.

MAJOR WILLIAMS:

Major Williams recalled the original work done by Colonel Boysen at W-PAFB employing 350 mc radar.

DR. HARTMAN:

Dr. Hartman referred to the discussion by Dr. Schwan regarding shortwaves and he said it was a much more refined experiment than anything that had been done previously with shortwaves. Dr. Hartman noted that nothing more than clinically applied heat should do the same thing or produce the same sort of pathological condition as noted by Dr. Schwan. He said that of all the patients treated with this type heat application or therapy not a single case of cataracts had been uncovered. Also, not a single patient complained of sterility from this hyperthermic therapy.

DR. FRICKER:

Dr. Fricker stated that histo-pathological examination of the tissue did not show changes that could not be attributed to a severe rise in temperature.

DR. HARTMAN:

Dr. Hartman reviewed some of the procedures used in hyperthermy in which some of the patients were exposed weekly and some twice weekly for long periods of time. He did not believe that this experience could solve the microwave question but felt that many things from these investigations could be applied to the current problem. He also took issue with Dr. Schwan by noting that work done in this country, (U.S.) was quite exacting. Dr. Hartman said that he was thoroughly familiar with the European work and that the quality of these investigations was not superior to that performed by the United States scientists.

DR. INGRAHM:

Dr. Ingrahm raised the question of microwave energy in relation to relief from paralysis. She also thought there was some evidence that this form of energy could induce paralysis. Dr. Ingrahm also posed this question: cataracts were assumed not to be produced by microwave energy simply because they were not looked for in the experimental animals involved or in humans exposed to microwave energies.

DR. FRICKER:

Dr. Fricker noted that although eye examinations for cataracts with a slit lamp were not a routine procedure, this technique should be made much more common and an effort should be made to define criteria.

B. EVIDENCE OF NON-THERMAL EFFECTS

Dr. Fricker commenced the discussion by reviewing the California incident in which a worker allegedly was killed by radar energy. Further investigation revealed that this person died of other causes.

DR. RICHARDSON:

Dr. Richardson discussed prolonged clotting time as induced by microwave energy. His group had noted that large doses of microwave radiation increased clotting time. He said a re-run of the same experiment produced the same results. For these experiments, data were collected from measurements of 400 samples obtained from experimental animals and treated with microwave radiation. The same number of samples were used for the Controlled. (See Appendix D).

COLONEL KNAUF:

Colonel Knauf noted that his group was attempting to develop enough data to substantiate the effects of microwave energy on clotting time. The results that he had obtained so far from blood from 75 different people showed about the same thing noted by Dr. Richardson, that is, prolonged clotting time after exposure to microwave energy. This increased clotting time was not shown in the Controlled or untreated group.

DR. FRICKER:

Dr. Fricker noted that this prolonged clotting time of blood after exposure to microwave energy was something they (Lincoln Laboratories) had wondered about for some time.

COLONEL KNAUF:

Colonel Knauf noted that his research group was studying this particular phenomena and he would appreciate any suggestions or data that members of this conference could provide.

DR. FRICKER:

Dr. Fricker asked if anyone could suggest what might be causing this particular change in blood clotting time since it appeared to be one of the non-thermal effects from microwave energy.

DR. CAMPBELL:

Dr. Campbell raised the question as to whether the animals were perspiring and suggested a look into possible loss of vitamin C.

DR. HARTMAN:

Dr. Hartman returned again to a discussion concerning the number of variables. He said that with a reduction in the number of variables, in this particular problem, data would be provided which would be more meaningful and which would allow the drawing of more definite conclusions. Dr. Hartman also noted that studies on prothrombin time should be undertaken since this problem is directly related to these changes.

DR. HERRICK:

Dr. Herrick reported that her organization had found it difficult to analyze the effect of induced fever on blood clotting time, blood pressure, and pulse rate, in their experimental animals (dogs). She said that full power output from their shortwave equipment, however, did not produce a single degree of fever when the entire animal was exposed. They succeeded in raising the body temperature of dogs by heating only the head. Dr. Herrick noted that a body temperature of 109° F was 100% lethal. In experiments where dogs were killed by excessive heat, the physician of their team became concerned about the state of the blood. The blood of the animals that expired to hyperthermy was in an almost solid state. The physical condition of the blood in these animals apparently differed significantly from the physical condition of the blood from animals exposed to microwaves. Dr. Herrick suggested further studies on the viscosity of blood and the effects temperature, and microwave energy have on this physical characteristic.

DR. FRICKER:

Dr. Fricker said weight changes in the animals his group had observed may be significant. A slight but general increase in weight was thought to be correlated with exposure to microwaves during the early portion of the exposure. As the length of treatment progressed, the rabbits tended to lose weight and they drank quantities of water to compensate for this loss. Dr. Fricker also noted that they had detected a slight fever in some of their experimental animals exposed to microwave energies.

F. NEED FOR A FALL OR WINTER CONFERENCE

Mr. Tallman opened the discussion by stating that two types of meetings have been considered: (1) purely scientific and (2) an administrative type. He stated that the consensus of opinion was that the two meetings should not be separated. He felt that the earliest meeting should take place 9-12 months from this date.

Mr. Tallman discussed the coordination responsibility that Dr. Heatherington had referenced earlier in the conference. Mr. Tallman assumes that the coordination responsibility has now been passed on to RADC. He stated that he plans to pass on information on a quarterly basis.

Dr. Schwan made some general comments concerning the meeting. He stated that he had a feeling of dissatisfaction during the entire conference. This was due partly to the fact that there was no opportunity to thrash things out. He would like to see a working symposium on various topics and have each broken down into sub-sections. For example, dosimetry. Mr. Tallman was in agreement concerning the working symposium. He made clear, however, that the future meeting which he was discussing involved a group the size of the present group. He suggested smaller size working groups on specific items as had been suggested by Major Williams earlier.

Dr. Fricker also agreed that smaller groups were needed for discussion on items of down-to-earth significance.

Final arrangements for another meeting were not made.

APPENDIX A

INVESTIGATION OF THE BIOLOGICAL EFFECTS OF ELECTROMAGNETIC RADIATION

Status Report

Prepared by:
George M. Knauf, Colonel, USAF (MC)
Griffiss Air Force Base, New York

I. Ionizing Radiation

A. Levels up to 200 R/hr have been measured from certain Klystrons.

B. Great concern at moment with regard to Dosimetry and tolerance standards.

1. Copper shell of high power tubes filters out most of soft X-rays. Remaining radiation has an effective energy level 3 or 4 times greater than broad spectrum X-radiation.

2. Small tubes in laboratory use emit X-radiation too low in energy to be measured by standard film technique. Requires microscopic examination of superficial layer of emulsion to detect minute evidence of change. Fairly reliable down to 8 or 10 KEV. Standard technique not reliable below 30 or 35 KEV.

3. Effective energy output of X-radiation from high power tubes has made it necessary to lower maximum allowable exposure level from 300 MR/wk to 100 MR/wk in our laboratories.

4. Standard ionization chamber type of instrument of no value in measuring X-radiation output of high power tubes because they are sensitive to R/F energy. We have established a project for the development of an instrument capable of giving wide scale, direct reading, instantaneous values.

5. Standards are being revised in many areas of interest.

   (a) New York State has just adopted a level of 100 MR/wk.

   (b) Stanford U. (one of our tube contractors) has just lowered their acceptable level to 100 MR/wk.

C. Preventive Medicine Aspects

1. Personnel are not adequately indoctrinated in the significance of this problem. Graphic displays, literature and classes have been introduced to correct this deficiency.

2. Psychological problem is a barrier. A.E.C. has an enormous advantage in that their goal is the production of increasing amounts of ionizing radiation. Workers expect and accept this fact. With us this energy is an impurity and is a rather accurate index of the poor efficiency of a tube. Engineers responsible for the design of the tube are quick to minimize the X-radiation output. They also evince a feeling adverse reports on X-ray output may influence the acceptance of their tube. They tend to cite the fact that no harm has resulted in the past. This does not hold true in considering our new high power tubes. Designers of power tubes resent the fact that "X-ray clamor" aids and abets the cause of the school which favors the lower powered triode as a source of high levels of R/F power.

3. We have adopted certain control measures--

(a) Published a regulation establishing control measures.

(b) Implemented a rigid film badge program.

(c) Posted all areas in which hazardous levels of X-radiation might be experienced.

(d) Accomplish constant surveillance of suspect areas by a program of area monitoring.

(e) Implemented a program of project monitoring to anticipate problems and insure adequate shielding provisions being built into design criteria.

(f) Provided shielded lead rooms for test of unshielded tubes in the laboratory.

(g) Have instituted a comprehensive eye survey (including a slit-lamp examination) to identify early effects if they occur.

II. <u>Microwave Radiation</u>

A. Effects program now centered at Rome. SAM contracts in the process of being transferred. 2.

B. The project documentation establishing this as a separate program for biological effects has been completed.

C. A maximum allowable ambient energy level of .01 w/cm^2 has been arbitrarily established and the field notified by wire. No point in time has been considered valid in the absence of data on effects of chronic exposure.

D. Research approach has been fairly well established.

1. Contracts

(a) Existing contracts transferred from SAM will be completed or, where indicated, will be modified to meet our requirements.

(b) Frequency spectrum will be sampled at 200 mc, 3,000 mc, 10,000 mc, 24,500 mc and 35,000 mc, investigating effects of whole body exposure, selected organs and tissues, single cells and enzyme systems, using varying power levels, pulsed and continuous wave, under conditions of acute, sub-acute and chronic exposure. In order to accomplish this work, certain contracts have been awarded.

(1) 200 mc - University of Buffalo - Progressing nicely - Good progress on instrumentation. Trend of growth stimulation in exposed chick embryos seen.

(2) 3,000 mc - University of Rochester - In final stages of negotiation. Propose to investigate along lines we suggest and would introduce enzyme studies early. Also want to explore possibility of additive effects resulting from exposure to both ionizing and R/F energies.

(3) 10,000 mc - University of California - Have contract now with SAM. Have all facilities and equipment for research at this frequency. Have expressed a desire to engage in a more comprehensive effort. Propose to re-negotiate their contract as soon as it is formally in our hands.

(4) 24,500 mc - No satisfactory proposal received. One from Armour Research Foundation requires re-working. Will solicit other sources.

(5) 35,000 mc - University of Miami - Equipment enroute from Rome - Some items in place. Very promising group. Work should begin during July.

2. In House

(a) Certain In House effort will be applied to a study to determine whether appreciable heating of deep structures may occur from exposure to microwave energy without noticeable skin temperature changes. Same frequency samples will be used. Where possible, human volunteers will be used from among patients in 2845th USAF Hospital to facilitate clinical evaluation.

(b) The very low end of the frequency spectrum is being explored for possible effects of clinical significance by the use of 27 mc pulsed generators. These have been placed in use in the 2845th USAF Hospital at Rome, the USAF Dispensaries at Stewart AFB and Syracuse AF Station, and the Naval Medical Center at Bethesda, Maryland. Effort is being directed toward effects on calcareous deposits in Bursitis, effects on liver function in normal individuals and those with acute and chronic Hepatitis, and effects on Prothrombin time in peripheral blood.

E. Preventive Medicine Aspects

Pending the accomplishment of the research described above, certain interim precautionary measures have been adopted.

1. Microwave Radiation Hazardous Areas have been defined as any environment where personnel may be exposed to microwave energy having a power density of .01 w/cm^2.

2. The practice of discharging the output of high power R/F generators into the surrounding area of a laboratry has been discontinued.

3. Steps have been taken to avoid directing radiating devices in free space toward any inhabited building or personnel grouping.

4. Personnel have been prohibited from performing any work on antennas, wave guide or feeder horn structures while the set is energized.

5. Monitoring is carried out in all populated areas in the laboratory complex to insure that the allowable personnel exposure level of .01 w/cm^2 is not exceeded.

6. Action has been taken to effect the development of an integrating R/F personnel dosimeter.

III. <u>Associated Biological Hazards</u>

The expanding application of microwave energy and ever increasing power have given rise to certain other problems of significance. These in short stem from the exposure of certain well known substances to a new and unexplored environment which results in the production of situations which are without precedent.

1. The expansion of our radar warning system to include the Arctic has necessitated a search for materials adaptable to use at extremely low temperatures. This can result in introducing known substances to an environment which results in a hazard with which we have had no previous experience. An example of such a situation occurred when Pyronal (containing 1, 2, 4 Trichlorobenzene) was employed as a diluent in transformers for the Dew Line and White Alice projects. This substance was chosen because it would keep the trans former filler viscid at low temperatures. However it was

later learned that under electrical load the filler warms sufficiently to volatilize the trichlorobenzene giving off toxic fumes in appreciable quantities. Our experience with this gas points to an inadequacy in published reports as to its effect on man. We have observed one individual who displays a very marked anaphylactic reaction to this substance when it is present in the atmosphere in minimal concentration. We are in the process of installing exhaust fans in all locations where these transformers are installed. This is an expensive procedure and could have been avoided by a more careful selection of a diluent. Steps are being taken at Rome to develop an adequate detector for this material.

2. The development of sources of high frequency electromagnetic energy at unprecedented power levels have produced a modality whose properties and potentialities are totally unknown. The effects of this new force on matter can result in situations and reactions extremely hazardous to man. An example of such a situation took place recently in connection with the use of sulf-hexafluoride (SF_6) in a pressurized wave guide. As power levels increase it has been found that transmission difficulties are encountered in moving this energy through a wave guide or hollow conductor. This transmission is greatly facilitated if the wave guide is filled with an inert gas under considerable pressure. Based on published characteristics and toxicological data SF_6 was selected as the gas best suited to this application. Arcing in the wave guide was found to liberate fluorine in large amounts. This phenomena has not been previously described and was identified in this case only because an alert Preventive Medicine Team, distrustful of all fluorides insisted on accomplishing animal exposures prior to acceptance of this technique for wave guide pressurization. All animals exposed for 30 minutes to this SF_6 after the energy had arced between wave guide walls died promptly. Gross Post Mortem examination revealed all had suffered massive pulmonary hemorrhage. The violent toxicity of this inert has after exposure to this energy points up the need to be alert for the presence of properties not previously recognized.

APPENDIX B

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BIOLOGICAL EFFECTS OF RADIO FREQUENCY ENERGIES
1940 - 1957

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APPENDIX C

SUMMARY OF RESULTS OF UHF RADIATION HAZARD EXPERIMENTS AT LINCOLN LABORATORY, MIT

Massachusetts Institute of Technology
Lincoln Laboratory
September 5, 1957

1. Object of Tests

To determine possible biological effects of intense RF radiation. Rabbits have been used as test animals, and have been subjected to whole body irradiation.

2. Method

Most of the exposures have taken place in a waveguide system, thus allowing the power absorbed by the test animal to be measured. The incident power density may be estimated but was not measured. Some additional experiments also were carried out in "free space."

Initial experiments led to a determination of the dosage that could be given without too much danger of killing the test animal. In approximate figures the dosage tends to become lethal after half an hour at 60 mw/cm^2, or after two hours at 30 mw/cm^2. Levels of 10 mw/cm^2 can be tolerated for hours with no apparent effect.

3. Tests

Series of rabbits were given repeated exposures at various levels, mostly 30 and 60 mw/cm^2. The animals which had been examined up to July 1957 are listed in Tables 1, 2, and 3. Tables 1 and 2 refer to the rabbits which have had complete ophthalmological examinations. Table 3 refers both to animals which have undergone complete autopsies and to those in which only the testes have been examined. Further autopsies and testicular examinations are in progress.

4. Results

The rabbits' eyes were examined by Drs. D. Cogan and D. Donaldson, of the Howe Laboratory, Massachusetts General Hospital, while the pathological examinations were undertaken by D. G. Curtis of the Harvard Medical School. As far as the animals listed in Tables 1, 2, and 3 are concerned, the results have all been negative. Dr. Cogan has seen nothing in the rabbits' eyes which he would attribute to the effects of RF radiation. Dr. Curtis has found nothing which he would attribute to RF radiation.

5. Further Examinations and Tests

Dr. Curtis still has a considerable number of rabbits to examine. In addition, some tests with rats will be undertaken this fall, the procedure and examinations will follow the lines of the rabbit tests.

Table 1 - Waveguide Exposures

Level mw/cm^2	Number of Rabbits	Exposure Time Minutes	Number of Exposures	Rate of Exposures	Time of last examination after last exposure (weeks)
10	2	60	3	weekly	11
	2	120	3	"	11
30	1	30	1	---	8
	2	60	3	"	11
	5	60	3	"	4
	1	60	8	"	2
	1	120	3	"	8
60	1	20	4	"	2
	3	20	5	"	1
	5	20	6	"	1
	12	20	10	daily	6
	2	30	3	weekly	11
	6	30	3	"	1
	2	30	7	"	1
	4	30	8	"	2
	1	60	1	---	10
Controls	37				
Died					
30	1	73	1		
	1	60	After 6 weekly exposures		
60	2	30	1		
	1	30	After 2 weekly exposures		
	2	60	1		

Table II - "Free Space" Exposures

Level mw/cm2	Number of Rabbits	Exposure Time Minutes	Number of Exposures	Rate of Exposures	Time of last examination after last exposure (weeks)
10	3	360	1	---	3
30	4	90	10	2/week	8
	1	120	1	---	1
	2	120	1	---	3
	2	120	2	weekly	--
60	1	15	1	---	9
	4	15	10	2/week	8
	2	30	2	weekly	4
	1	60	1	---	13
Controls	8				
Died					
30	2	120	1		
60	3	30	1		
	2	49	1		
	1	60	1		

Table III - Complete Autopsies

Level mw/cm^2	Number of Rabbits	Exposure Time Minutes	Number of Exposures	Rate of Exposures
.03	1	120	3	weekly
	1	60	8	---
	4	60	1	---
.06	2	20	6	weekly
	4	30	8	"
	1	60	1	"
Controls	8			
Testicular Examination Only (in addition to above)				
.06	12	20	10	Daily
Controls	15			Sacrificed approximately 2 months after last exposure
.06	9	20	5	Daily
Controls	9			Sacrificed four days after last exposure
.06	9	20	5	Daily
	9			Sacrificed ten days after last exposure

ABSTRACT OF REPORT MICROWAVE EXPOSURE CONFERENCE

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1. Pathologic effects of three centimeter Microwaves of low magnitude.

Photographs of histologic sections were presented to support the view that three centimeter wavelength microwaves of $25 mw/cm^2$ magnitude created pathologic damage in albino rats if the exposure were over prolonged periods. Two conditions were presented. In one condition, animals were exposed for 30 minutes duration for 10 or more exposures. With another condition the animals were exposed once, for periods of 4 hours or longer.

Reported damages involved areas of the brain, lungs, liver, muscle, and kidney. Specific damages included edema, protein loss extravascularly, blood cellular loss into tissues, and bleeding from vessel rupture. In the brain, lungs, liver and kidney there was evidence of tissue cellular damage.

2. Demonstration of dosimeters to assay accumulated microwave energy.

Two models of dosimeters were demonstrated, both smaller than a pack of cigarettes. These miniature transistor-amplified instruments use a gel capsule housing a thermistor element for the sensing element and record the amplified resultant of field strength and time on a meter. The response follows the curve of temperature induction in living avascular tissues resulting from microwaves, and follow the time constant of both temperature rise and decay in these living tissues. This feature makes the instrument practical for a safety dosimeter for use by personnel in radar energy fields. Sensitivity of the instrument is adjustable. Characteristics of the instruments were discussed.

APPENDIX E

OFFICE OF THE BASE SURGEON
GRIFFISS AIR FORCE BASE, NEW YORK

MICROWAVES AND THEIR BIOLOGICAL EFFECTS
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This listing has been prepared in cooperation with the Directorate of Technical Services, RADC.

APPENDIX F

DETERMINATION OF POWER DENSITY AT MICROWAVE FREQUENCIES

by

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The determination of free-space power density at microwave frequencies is relatively simple and can be accomplished with a minimum of equipment if the measurement theory is thoroughly understood. Basically, the determination of power density involves probing of the r-f field with microwave horns, half-wave dipoles, or some other structure of known properties and measuring the received power flowing through a point at the end of the transmission line. From this measurement the power density can easily be calculated using the following formula:

$$Po = \frac{4\pi Pr}{\lambda^2 Gr}$$

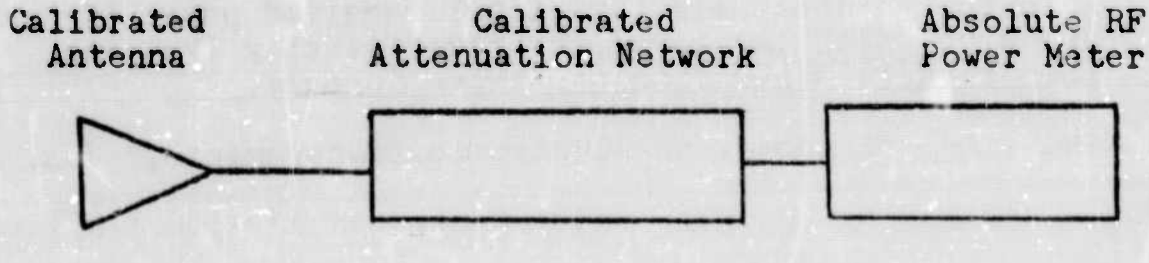
where Po = Power density = watts/cm^2

Pr = Received power = watts

Gr = Absolute gain of the receiving probe (above an isotropic radiator)

λ = Wavelength = cm

In practice, due to the non-availability of medium-level power meters in the microwave range, it becomes necessary to use bolometer bridges and appropriate attenuating elements to decrease the received power to levels acceptable to the low-power bridge. It, therefore, follows that most microwave power density measurements can be accomplished by the utilization of three (3) appropriately selected microwave components as shown in the following block diagram.



Each component shown above is available in one form or other to enable almost complete coverage of the microwave spectrum. A list of typical equipment which could be used to cover an appreciable portion of the microwave spectrum can be found in the attached memorandum. It is felt that a large majority of presently available radiating systems could be analized by utilizing the equipment on this list.

Procedure

Briefly the procedure for determining the free-space power density emanating from a microwave radiator is discussed below:

1. Pre-measurement Procedure:

   a. Select an R-F antenna or probe, R-F power meter and appropriate attenuating element for the frequency range of interest.

   b. Calibrate or determine the absolute antenna gain (gain above an isotropic radiator) at the measurement frequency.

   c. Calibrate or determine the attenuation of the attenuating network.

2. Measurement and Computation Procedure:

   a. In probing the radiated field it is always good practice to perform initial measurements at some practical distance from the radiator and gradually work in toward the source of radiation. This provides some safeguard for personnel performing the measurement.

   b. With the components assembled as shown in the above block diagram, orient the receiving antenna so as to pick up the maximum radiated field. The best alignment will be achieved by peaking the power meter indication. The power meter reading should then be recorded. This reading can then be converted to the total received power (Pr) by taking into account the loss of the attenuating element. Example, if the attenuating element had a 20db loss, Pr = 100 x meter reading.

   c. With the antenna gain (Gr) total received power (Pr) and wavelength (λ) known, the power density (Po) can then be determined from the above formula.

Reference - Wind, Moe, "Handbook of Electronic Measurements," Vol. II.*

*Handbook was sponsored by the USAF under Contracts AF30(602)-677 and AF30(602)-1578.

Supplement

Prior to recommending the establishment of a personnel tolerance level for radio frequency energy, the feasibility and efficiency of measuring this radiation were thoroughly explored. The maximum allowable ambient level of .01 watt/cm^2 can be determined adequately in the frequency range of Air Force R/F power generators by means of standard and stock devices. The techniques will be familiar to qualified personnel working in this field.

Questions regarding measuring procedures may arise from personnel unfamiliar with electronic equipment and/or without access to appropriate guidance. As a tentative aid to these personnel, the following list of equipment and frequency ranges is included.

1. Power Meters (To be used with appropriate probes (antennas).

   1-4 KMC: Bridge Summation - AN/URM-23

   4-10 KMC: Bridge Summation - AN/URM-24

   23.5 to 24.5 KMC: Meter, RF Power TS-254

   With Microwave Power Meter Hewlett-Packard Model 430C/

   a. DC to 10 KMC: Thermister Mount Model 477B

   b. 8.2-12.4 KMC: Waveguide Thermister Mount Hewlett Packard Type X487B

   c. 12.4-18 KMC: Detector, Barretter Mount Hewlett Packard Type 485C

   d. 18-26.5 KMC: Waveguide Thermister Mount Hewlett Packard Type K487B

2. Probes (Antennas)

   Below 320 MC use calibrated dipole.

   320 to 1120 MC: Antenna AS-770/URM-16

   1170 to 3400 MC: Antenna AS-771/URM-16

   3400 to 10,000 MC: Antenna AS-772/URM-16

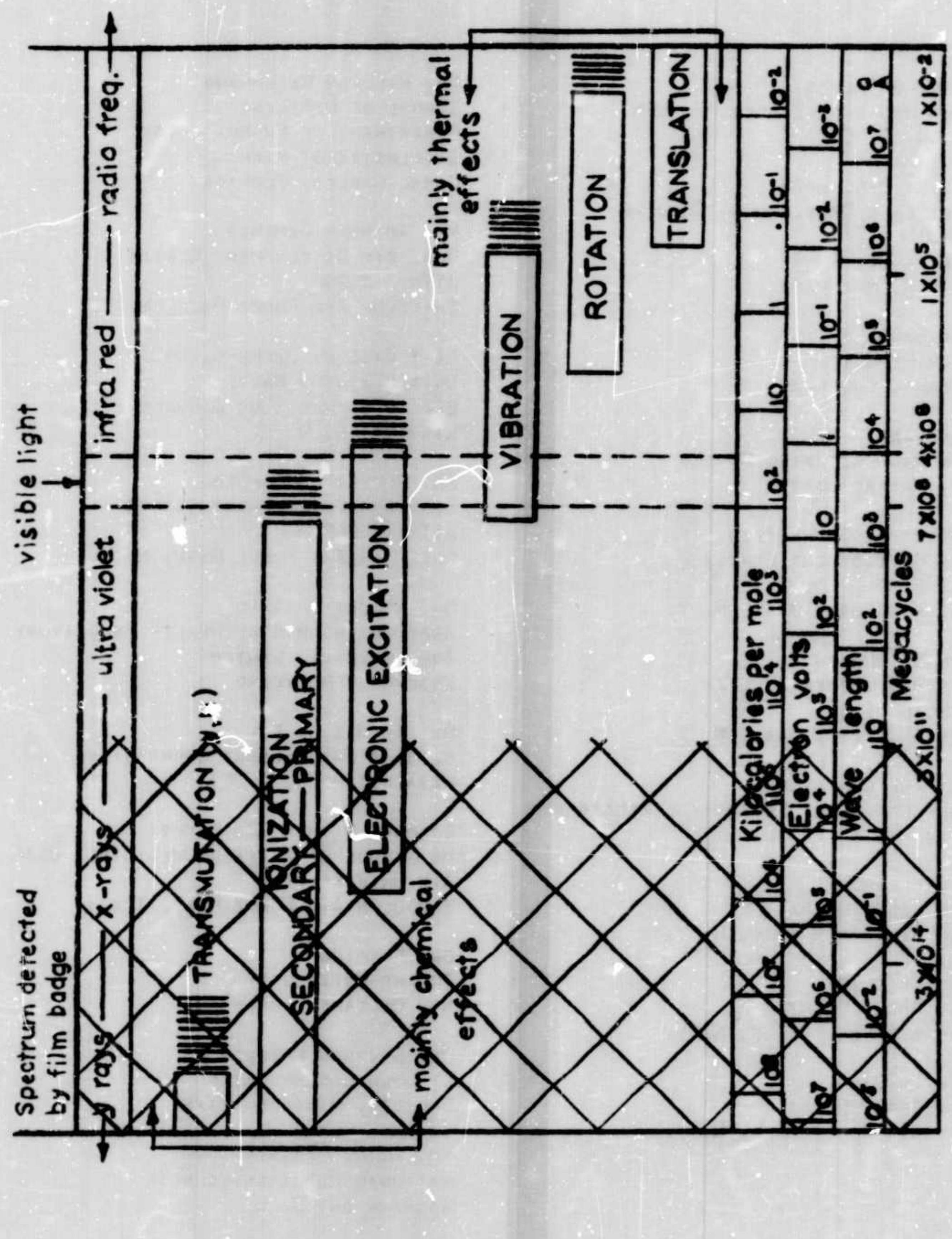
8.2 to 12.4 KMC: Antenna AT-156/U

12.4 to 18 KMC: Antenna AT-157/U

18 to 26.5 KMC: Antenna AT-158/U

Notes

Depending on frequency and power coupled to the line, calibrated cables and/or attenuators can be used to decrease the power received to a level acceptable to the particular power meter.



ELECTROMAGNETIC RADIATION

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