U. S. NAVAL AIR ENGINEERING CENTER

PHILADELPHIA, PENNSYLVANIA

Aerospace Crew Equipment Laboratory

HEATING OF LIVING TISSUES

By H. P. Schwan, A. Anne,
and L. Sher

NAEC-ACEL-534   18 FEBRUARY 1966

DDC AVAILABILITY NOTICE

U.S. Government agencies may obtain copies
of this report direct from DDC. Other
qualified DDC users should request through
the Chief, Bureau of Naval Weapons,
Washington, D. C. 20360.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

ADMINISTRATIVE INFORMATION

This report was prepared in the Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia, Pa., as part of Contract N156-43468. BUWEPS Problem Assignment 005-AE13-18 (WEPTASK RAE 13C 005/2001/R005 01 01), and BUMED Work Unit MR005.13-6003.2 authorized the work reported here. Principal investigator was Professor Herman P. Schwan, Head of the Electro-medical Laboratory. Dr. E. Hendler, Manager, Life Sciences Research Group, Aerospace Crew Equipment Laboratory, Naval Air Engineering Center acted as contract monitor. The work on this contract was accomplished between June 1963 and September 1965.

This report has been reviewed and is approved.

HENRY G. WAGNER
CAPT, MC, USN
Director

iii

ABSTRACT

A central forehead area of 4 subjects was exposed to free-field, 10 cm microwave irradiation and the reaction time to onset of warmth sensation measured. Subjective awareness of warmth was found to be only a rough indication of personal hazard, based upon the currently accepted safety standard of 75 mw/cm^2 for 2 min.

1. INTRODUCTION:

Health hazards, resulting from the exposure of mankind to strong sources of non-ionizing electromagnetic radiation, have been discussed.[1,2,3,4] The harmful effects of excessive amounts of radiation either result from a general rise in total body temperature or are limited to selective temperature rises of sensitive parts of the body such as the eye. Present indications are that the effects of such radiation are caused solely by the heat resulting from the absorbed energy. It has been assumed, in the case of total body irradiation, that a fever corresponding to a temperature rise greater than $1^{\circ}C$ is intolerable. Based on this concept a tolerance dosage of 10 milliwatts per square centimeter of total body absorption was recommended for the frequency range of interest to mankind. One of the purposes of this study is to investigate whether a person, in absence of knowledge of the value of power density, can realize the hazard through the sensation of warmth. Another reason is given by the desire to learn more about the mechanism responsible for heat sensation.

In this study, human subjects are irradiated with 10 cm electromagnetic waves to determine threshold sensations of warmth in terms of the incident power density. The subject, sitting in a shielded room, exposes only his forehead through an aperture 7 cm in diameter. As the microwave power is turned on and off, the subject

reports his sensations of warmth or no warmth by means of suitable switches. The forehead area was chosen for exposure for the following reasons[5]:

      (1)   It provides a relatively flat surface which could be exposed conveniently so that a uniform distribution of incident energy was assured.

      (2)   It is one region of the body surface characterized by its remarkably stable temperature, in spite of appreciable changes in environmental temperature.

      (3)   It has numerous temperature receptors which are evenly distributed over the area.

      Calibrations of two types were conducted:

      (1)   The distribution of microwave intensity in the aperture was determined experimentally. It was found that the power density at the edge of the aperture falls to about half of that at the center.

      (2)   The temperature rise that would occur in the skin was determined experimentally using a skin simulant. The temperature rise was found to be directly proportional to the incident power density.

Theoretical calculations were performed in order to investigate the dependence of the threshold sensation of warmth on the thickness of the forehead skin. From calculated values for the coefficient of absorption of microwave energy and for heat developed per unit volume in the skin, it was observed that the threshold sensation of warmth does depend somewhat on the thickness of forehead skin. On the basis of the data obtained, it is expected that the threshold of sensation will vary by about ±10%.

2. EXPERIMENTAL SET-UP:

A special room was built to shield the seated human subject while allowing the radiation to strike only his forehead. The room, 3' wide, 4' deep and 6' high, is irradiated on one of the 3' x 6' walls. On this front wall, a microwave absorbing material (Eccosorb) absorbs all radiation not incident on a 20 cm circular aperture in the absorber (figure 1). Through the aperture can be seen a second, 7 cm aperture in a thinner absorbing material (Teledeltos paper with a surface conductance of 377 ohms). A copper sheet backs up the absorbing material to give positive protection to the subject; any microwave energy that passes through the absorbing materials is reflected from the copper sheet. Thus, the subject is completely shielded except for the 7 cm circular aperture. A spacing of one inch is provided between the copper and Eccosorb. Heat developed in the Eccosorb is carried out by air pumped through this space. The temperature inside the chamber is kept constant by means of an air conditioning system.

3. CALIBRATIONS:

(1) Uniformity of field in aperture:

In order to investigate the microwave field distribution in the aperture, a circular acrylic plastic chamber with a diameter of 7 cm was constructed. A plastic membrane about 0.05 mm thick was stretched across the open face of the chamber and held in place with an acrylic plastic lock-ring. The chamber was filled with water. A sponge was also placed in the chamber to retard the heat convection in the water. Twenty-one copper-constantan thermocouples were used to measure temperatures at the center and around two concentric circles in the chamber (figure 2). The outer circle, 5.8 cm in diameter, contains 12 thermocouples and the inner circle, 3 cm in diameter, 8 thermocouples. Twenty-one identical thermocouples were also arranged to measure the ambient air temperatures around the immediate vicinity of the chamber. The chamber was exposed to the microwave radiation. The temperature rise during the linear transient period was measured at the twenty-one locations inside the chamber. Figure 3 shows the relative temperature rise as a function of time at the center of the chamber. During the transient period of about eight minutes, the temperature increases linearly with time indicating that there is no loss of heat. The use of the sponge to retard heat convection and the restriction of temperature measurements to the

linear transient period insured that the temperature rise should be accurately proportional to the absorbed and incident power density. Figure 2 shows the relative values of the power density at different locations in the aperture. It can be seen that the power density is a maximum at the center of the aperture and falls to about half of that value near the boundary. The power density is nearly constant on a given concentric circle around the center of the aperture.

(2) Temperature rise in irradiated skin:

In order to study the temperature rise that would occur in the skin irradiated by the microwaves, the plastic chamber described above (figure 2) was used as a skin simulant. A liquid layer of about 1.5 cm is formed when the chamber is filled with water. Temperature measurements in the water were made by connecting the thermocouples in series. The output of the thermocouples in the water layer was bucked against that of the thermocouples in the ambient air around the immediate vicinity of the chamber. An independent heating system of accurately-measured resistance, constructed of constantan wire, was placed in the liquid to determine the heat dissipation constant of the simulant. All measurements were made with the simulant located behind the aperture in the shield, where the subject's forehead would be.

Distilled water was used to fill the skin simulant instead

of a solution having electrical properties identical to those of the skin (table 1). The latter could be made up of a mixture of water, dioxane and KCl, but this solution would decompose the plastic. The effect of this substitution, having a dielectric constant of 78 and a conductivity of 16 mmhos/cm, rather than 42 and 20, is to lower the absorption coefficient. But, the change would be less than 10% as can be seen from Table 1.

The heat dissipation constant (D) of the skin simulant is defined as the increase in heating rate required to raise the steady-state temperature of the simulant by one degree.

$$D = \frac{\Delta p}{\Delta T}$$

where Δp is change in heat rate and ΔT is resulting change in steady-state temperature. The heat dissipation constant was determined by sending a known amount of electric current through the heating wire in the simulant until a steady-state thermal condition was established (figure 4). It can be seen from figure 4 that approximately two hours were required to realize steady-state thermal conditions. Figure 5 shows the relationship between the power input into the simulant and the resultant steady-state temperature in the simulant. The slope of the curve in figure 5 represents the heat dissipation constant.

Analogous to this procedure, the simulant was irradiated with microwaves at a number of known power density levels. Once

again, the heating was continued until a steady-state temperature
was established. Figure 6 shows the relationship between the incident
microwave power density and the temperature rise in the simulant.
Using the heat dissipation constant already found, the power absorbed
by the simulant was readily calculated.

The coefficient of absorption is defined as the ratio of
the power absorbed to the power incident on the cross-section
of the simulant. Table 2 shows that this coefficient for the simulant
is independent of incident power density. The table also includes the
values of the coefficient calculated by measuring the temperature rise
in the simulant during the linear transient of the heating period. The
excellent agreement supports the validity of these measurement techniques.

4. THEORETICAL CALCULATIONS:

The depth of penetration is 1.0 cm in the skin (Table 1). In general the values of thickness of skin may vary from 0.2 to 0.6 cm. If the depth of penetration is greater than the thickness of skin, it was shown[1] in the case of total body irradiation that (1) the coefficient of absorption and (2) the heat development in skin depend on the thickness of skin. To learn whether this variability is excessive and unpredictable or not, several calculations were conducted for the case of the forehead of a person. For these calculations a model was assumed in which electromagnetic plane waves pass from air, with normal incidence, through a layer of skin to a semi-infinite medium of bone, as indicated in figure 7.

1) Coefficient of absorption

The coefficient of absorption was calculated as a function of skin thickness d. Denoting dielectric constant and conductivity by ϵ and $\varkappa$ respectively, and using subscripts for each material (1-air, 2-skin, 3-bone), it can be shown that the coefficient of absorption, s, is given by

$$S = 1 - |\Gamma|^2$$

where Γ is the coefficient of reflection which is defined as the ratio of reflected power to the incident power.

$$\Gamma = \frac{(1-\sqrt{\epsilon_2}^*)\,(\sqrt{\epsilon_2}^* + \sqrt{\epsilon_3}^*) + (1+\sqrt{\epsilon_2}^*)\,(\sqrt{\epsilon_2}^* - \sqrt{\epsilon_3}^*)\,e^{-2k_2 d}}{(1+\sqrt{\epsilon_2}^*)\,(\sqrt{\epsilon_2}^* + \sqrt{\epsilon_3}^*) + (1-\sqrt{\epsilon_2}^*)\,(\sqrt{\epsilon_2}^* - \sqrt{\epsilon_3}^*)\,e^{-2k_2 d}}$$

with

$$k_2 = j\,\frac{2\pi}{\lambda}\,\sqrt{\epsilon_2}^*$$

= propagation constant in the skin

d = thickness of the skin

$$\epsilon_2^* = \epsilon_2 - j\,\frac{\varkappa_2}{\omega\,\epsilon_1}$$

= complex dielectric constant of the skin

$$\epsilon_3^* = \epsilon_3 - j\,\frac{\varkappa_3}{\omega\,\epsilon_1}$$

= complex dielectric constant of the bone

λ = wavelength in air

Figure 8 shows the coefficient of absorption as a function of skin thickness d. The coefficient of absorption undergoes damped oscillations for d = 0 to 3 cm and is independent of d for d > 3 cm. In general, only values of d from 0.2 up to 0.6 cm are of practical interest. In this range the coefficient of absorption varies between 30 and 42 percent, values fairly close to 45% which pertain if skin were completely absorbing (d = ∞). The threshold sensation of

warmth depends, therefore, somewhat on the thickness of the
forehead skin and may vary slightly when different human subjects
are used. By assuming a value of 36% an error of at most $\pm 6\%$ is
made in the coefficient of absorption.

2) <u>Heat development in skin</u>

The heat developed per unit volume in the skin was
calculated as a function of the depth in skin (Figure 7) for different
values of skin thickness (d). Following the method given in Ref. 1,
heat development per unit volume in skin is given by

$$H = \frac{\varepsilon_o^2}{2} e^{-2\alpha_2 d} \times_2 \left[\frac{1}{2\alpha_2} \left\{ P_2^2(1-e^{-2\alpha_2 d}) - (1-e^{2\alpha_2 d}) \right\} \right.$$

$$\left. + P_2 \left\{ \sin \phi_2 - \sin(\phi_2 - 2\beta_2 d) \right\} \right]$$

where

ε_o = Incident electric field strength in air

$k_2 = \alpha_2 + \beta_2$ = propagation constant in skin

α_2 = Attenuation constant in skin

β_2 = Phase constant in skin

$$p_2 = \frac{\sqrt{\varepsilon_2}^* - \sqrt{\varepsilon_3}^*}{\sqrt{\varepsilon_2}^* + \sqrt{\varepsilon_3}^*} = P_2 e^{d\phi_2}$$

= complex reflection coefficient at the boundary between

skin and bone.

The results of these calculations are shown in figure 9,
in which the heat development per unit volume is calculated as
a function of depth in skin for various values of thickness of skin.
The curves were calculated for an incident power density, P, of 1
milliwatt/cm^2, which corresponds to an electric field strength in
air (ϵ_o) of $\sqrt{377P} = \sqrt{0.377}$ volts/cm. As seen from the figure, the
heat rate per unit volume depends upon the skin thickness. The
data support the conclusions made from the calculations of
coefficient of absorption.

5. EXPERIMENTAL RESULTS:

The forehead skin of four subjects was irradiated with microwaves to determine the threshold sensation of warmth. The forehead of the subjects was placed behind the aperture in the shield. An arrangement of switches and relays which turned on an electric clock and applied the high voltage to the magnetron of the microwave generator simultaneously, was used to record the reaction time of the subjects. The subjects indicated the sensation of warmth by closing another switch which turned off the electric clock and the microwave power simultaneously. Each subject was irradiated five or more times in one experiment and the reaction times were noted. The experiments were conducted two times per day on each subject. The subjects were irradiated with two different levels of microwave power density.

Table 3 shows the average reaction times and their standard deviations for four different subjects at power densities of 56 and 74 milliwatts/cm^2. It can be seen that the reaction time varies between different subjects. This variation in reaction time may only in part be due to the variation in the thickness of forehead skin of the subjects. The reaction time also varies for each subject as indicated by the standard deviation. Table 4, for example, shows the reaction time of subject No. 1 as determined in different experiments for a power

density of 74 multiwatts/cm^2. These readings were obtained over a period of two weeks.

Table 3 indicates that there is no proportionality between the power density and the reaction time. Power densities higher than 74 milliwatts/cm^2 were not available due to the limitation of the output of the microwave generator. Power densities lower than 56 milliwatts/cm^2 were not used because long exposures were needed and the subjects were becoming impatient and tired.

6. CONCLUSIONS:

Human subjects are irradiated with 10 cm electromagnetic waves to determine whether a person, in the absence of knowledge of the value of power density, can realize the hazard through the sensation of warmth. The forehead area of the subject was used for exposure. The tolerance dosage which was established by H. P. Schwan is 10 milliwatts per square centimeter of total body absorption. Hence, we were reluctant to expose persons to 100 mw/cm^2 particularly on forehead. Even though the number of subjects used is too small, there is some significance in the results obtained.

If a person's forehead is exposed to microwave radiation the time which elapses before he is aware of a sensation of warmth is here called his reaction time. For 10 cm waves, this reaction time was studied for four subjects, with a minimum of 30 exposures for each. It was found theoretically that the reaction time should depend upon the thickness of the irradiated skin. For the subjects tested, the reaction times varied between 10 and 100 seconds for a power density of 75 milliwatts per square cm. It was also found experimentally that the reaction time is not linearly proportional to the reciprocal of the incident power density. The currently accepted safety standard for microwave irradiation says that 75 mw/cm^2 can be safely tolerated for two minutes. The average reaction times measured in these experiments varied between 15 and 73 seconds. However,

these reaction times represent the minimum times for which an aware subject under ideal environmental conditions could detect the slightest perceptible sensation of warmth. Since the reaction times were found not to be linearly proportional to the reciprocal of the incident power density, it can be concluded that the subjective awareness of warmth is not a very good indication of personal hazard. It can, however, be roughly used for that purpose.

Two of the four subjects are northerners and the other two are southerners. The southern subjects have higher thresholds of sensation of warmth than those from northern climates.

The original hope of free field procedures to obtain uniform irradiation over the forehead could not be fulfilled despite considerable efforts. However, the experimental technique used is good, but the same results might have been obtained by pressing the aperture of a waveguide against the necessary part of the body. Because of high power density level at the forehead, it is better to choose some other part of the body. This will also remove (1) fear of brain damage and (2) uncertainty of applied energy due to the thinness of the skin over the skull.

References:

1. Schwan, H. P. and Li, K.: Hazards due to total body irradiation
    by radar, Proc. I.R.E., Vol. 44, No. 11, pp.1572-1581,
    November 1956.

2. Schwan, H. P. and Li, K: The mechanism of absorption of
    ultrahigh frequency electromagnetic energy as related to the
    problem of tolerance dosage, I.R.E. Trans. PGME, Volume
    4, pp. 45-49, February 1956.

3. Ely, T.S. and Goldman, D.E.: Heat exchange characteristics
    of animals exposed to 10 cm microwaves, I.R.E. Trans.
    PGME-4, pp. 38-43, February 1956.

4. Hines, H. M. and Randall, J.E.: Possible industrial hazards
    in the use of microwave radiation, Elec. Eng. Vol. 71, p.879, 1952.

5. Hendler, E., Hardy, J. D. and Murgatroyd, D.: Skin heating
    and temperature sensation produced by infrared and microwave
    irradiation, in temperature - its measurement and control in
    science and industry, Vol. 3, Part 3, Reinhold Publishing Corp.,
    New York, N.Y.

Table 1.

Dielectric Properties of Water and Skin

	Water	Skin
Dielectric constant	78	42
Conductivity	16	20 mmho/cm
Depth of Penetration	1.6	1.0 cm
Absorption coefficient	37%	45%
Reflection coefficient	63%	55%

Frequency = 2880 Mc/s.

Table 2.

Results of Calibration of Skin Simulant

Incident Power Density mw/cm^2	Incident Power mw	Temperature Rise		Power absorbed		Coefficient of Absorption	
		Steady State $^o{}_c$	Transient State $^o{}_c$/minute	Steady State mw	Transient State mw	Steady State %	Transient State %
18.5	714	1.84	.085	366	351	51	49
37.1	1428	3.82	.174	760	719	53	50
55.6	2142	5.44	.214	1090	884	51	51
74.2	2857	7.18		1442		51	

Table 3.

Reaction times of subjects

Subject	Incident Power density mw/cm^2	Reaction Time	
		Average sec	standard deviation sec
1.	74	38.3	12.7
	56	49.4	11.8
2.	74	32.6	11.3
	56	73.9	25.6
3.	74	72.8	19.8
	56	No response up to 180 sec.	
4.	74	14.8	6.2

Table 4.

Reaction times of subject No. 1

Experiment Number	Number of runs	Reaction Time	
		Average	Standard Deviation
1	5	31.8	9.3
2	7	48.6	11.2
3	6	42.3	9.4
4	7	25.6	5.8
5	7	43.1	10.0

Polystyrene foam

Spacer ring
(also serving as
air deflector)

Air

Skin simulant
(Water-filled plastic
chamber)

Incident Microwave Field

Thermocouple
leads

Plywood

Air

Copper sheet

Teledeltos paper
(377 ohm)

Microwave absorber
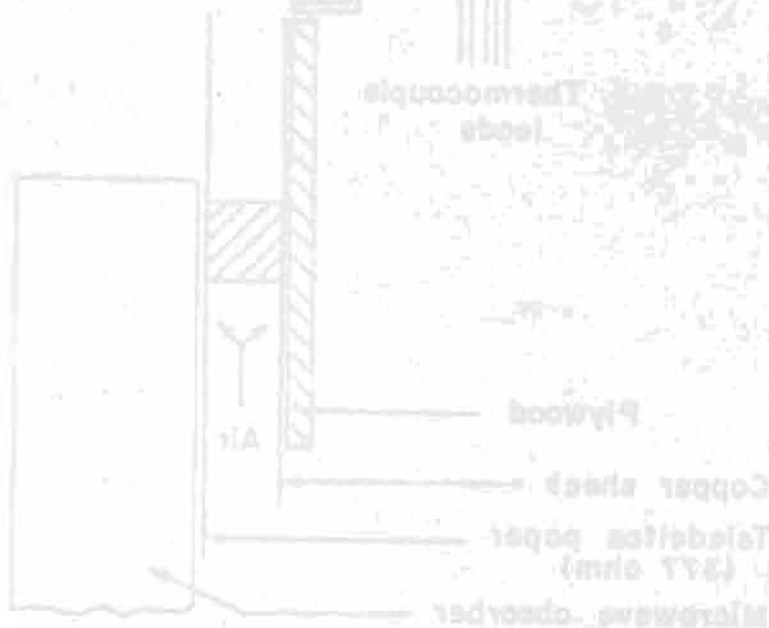
FIG. I   SKIN SIMULANT POSITIONED IN APERTURE.
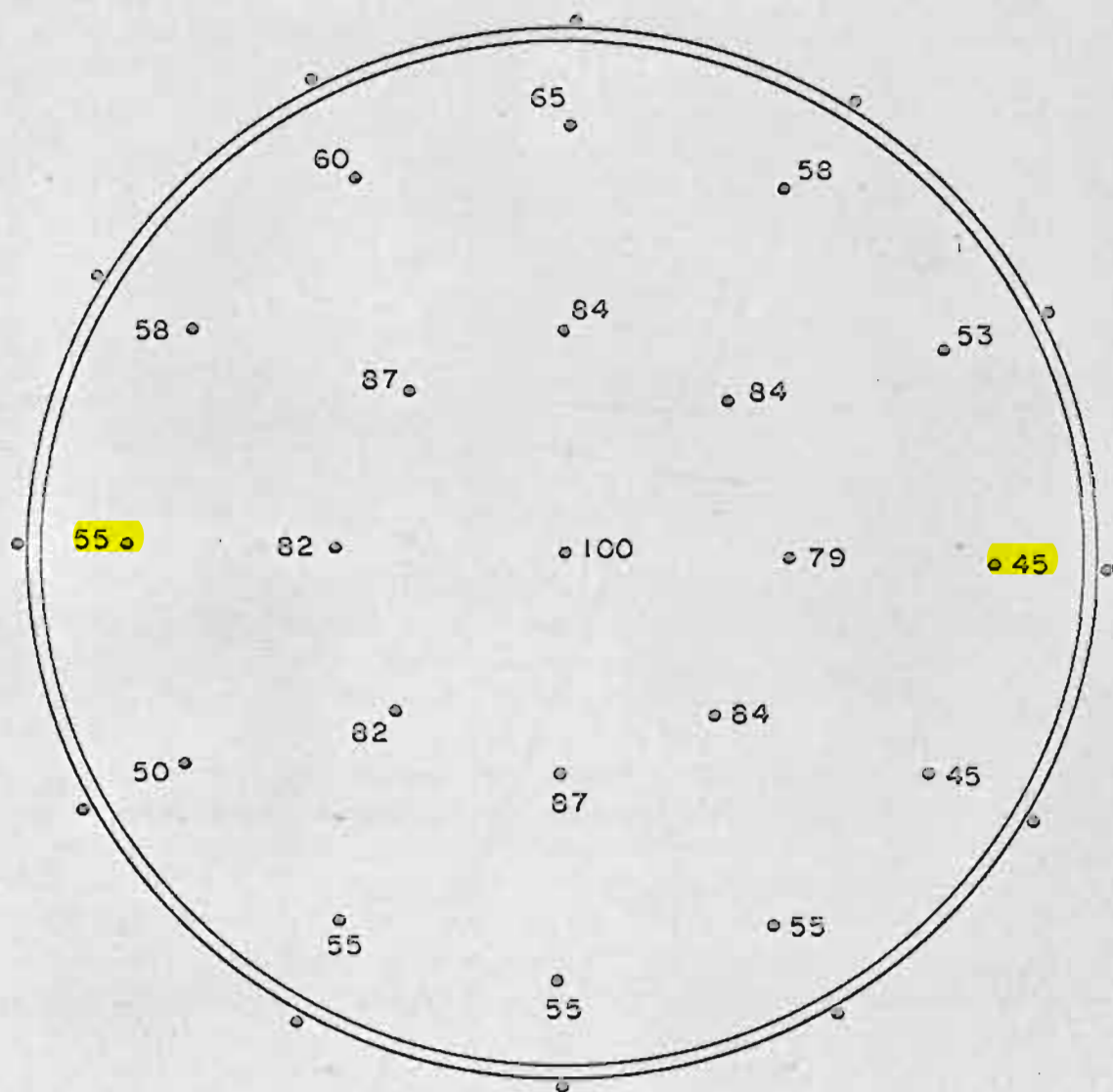
The numbers represent the relative values of power density.

FIG. 2   SKIN SIMULANT SHOWING POSITION OF THERMOCOUPLES.
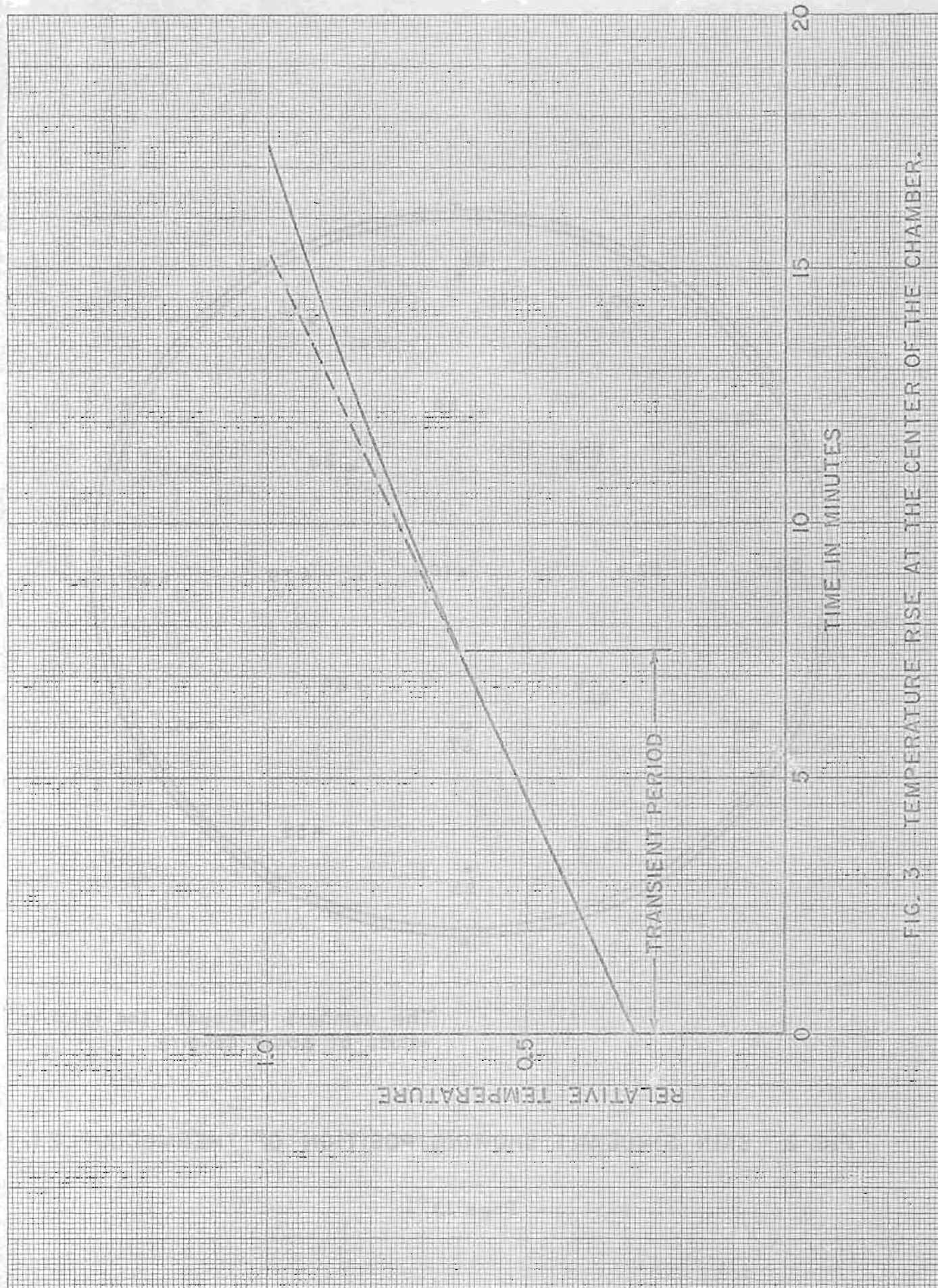
FIG. 3   TEMPERATURE RISE AT THE CENTER OF THE CHAMBER.
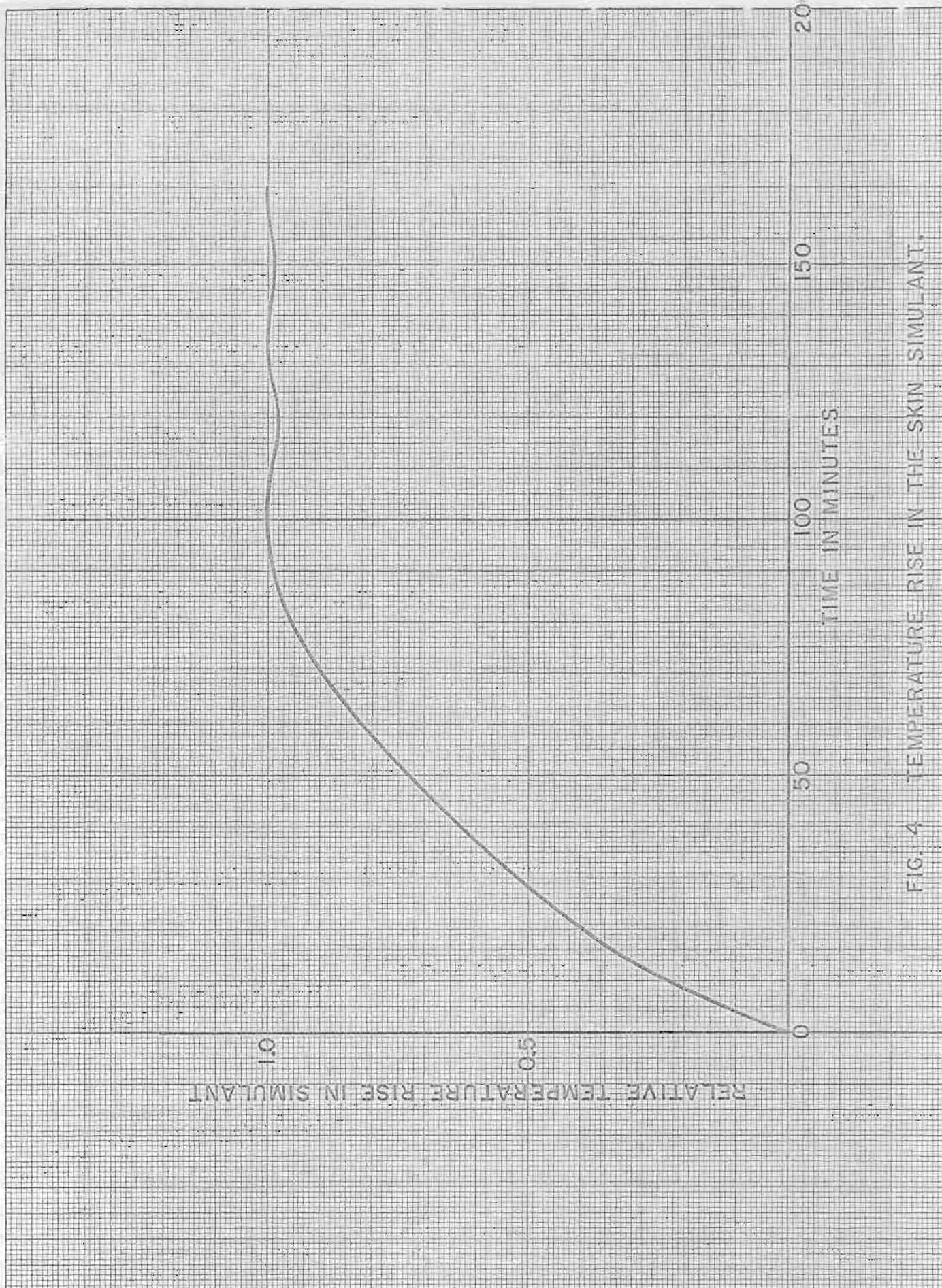
FIG. 4   TEMPERATURE RISE IN THE SKIN SIMULANT.

Heat dissipation constant 200 mw/°c

POWER IN mw

TEMPERATURE RISE IN °c
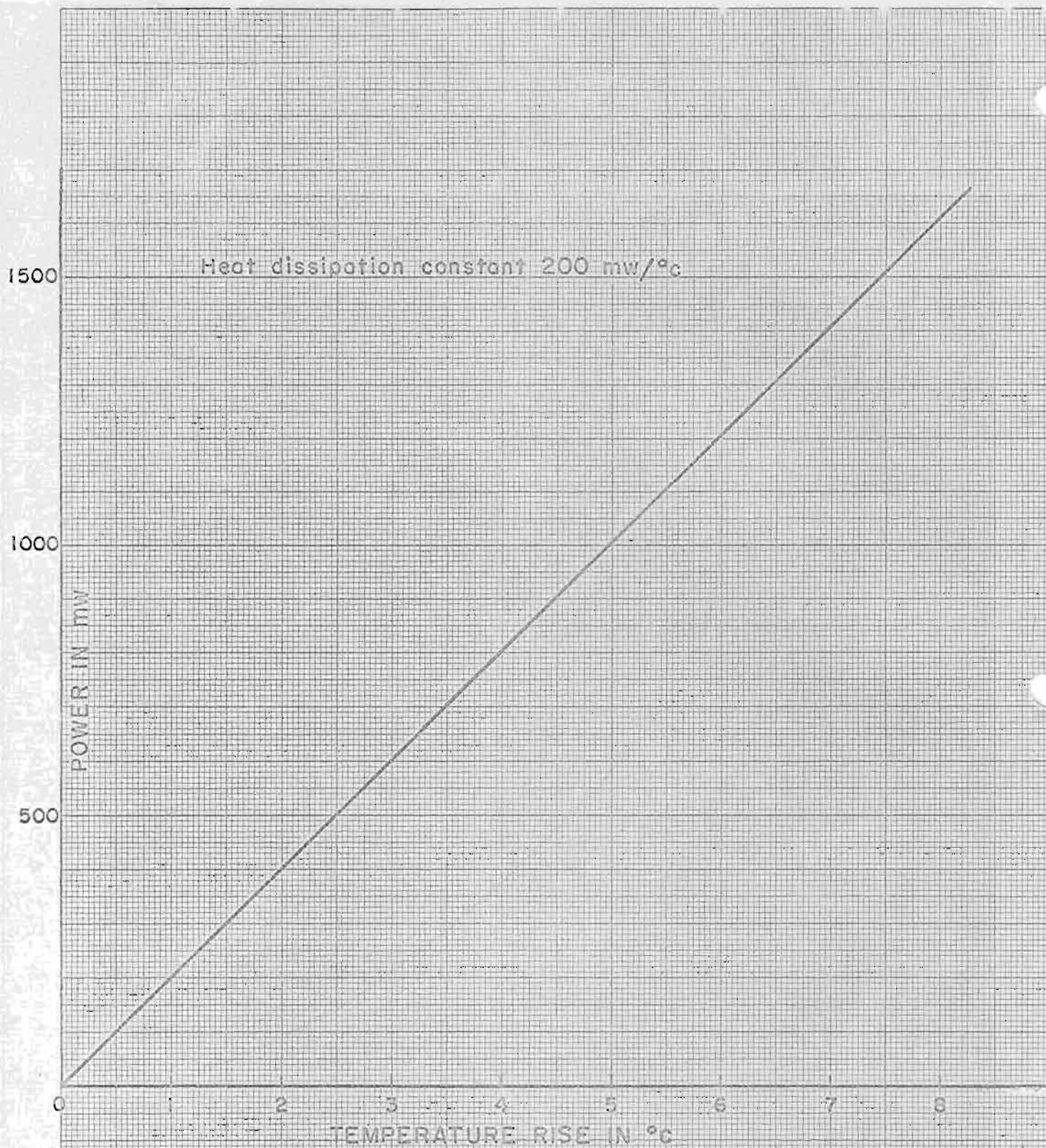
FIG. 5 HEATING OF SKIN SIMULANT BY DIRECT CURRENT
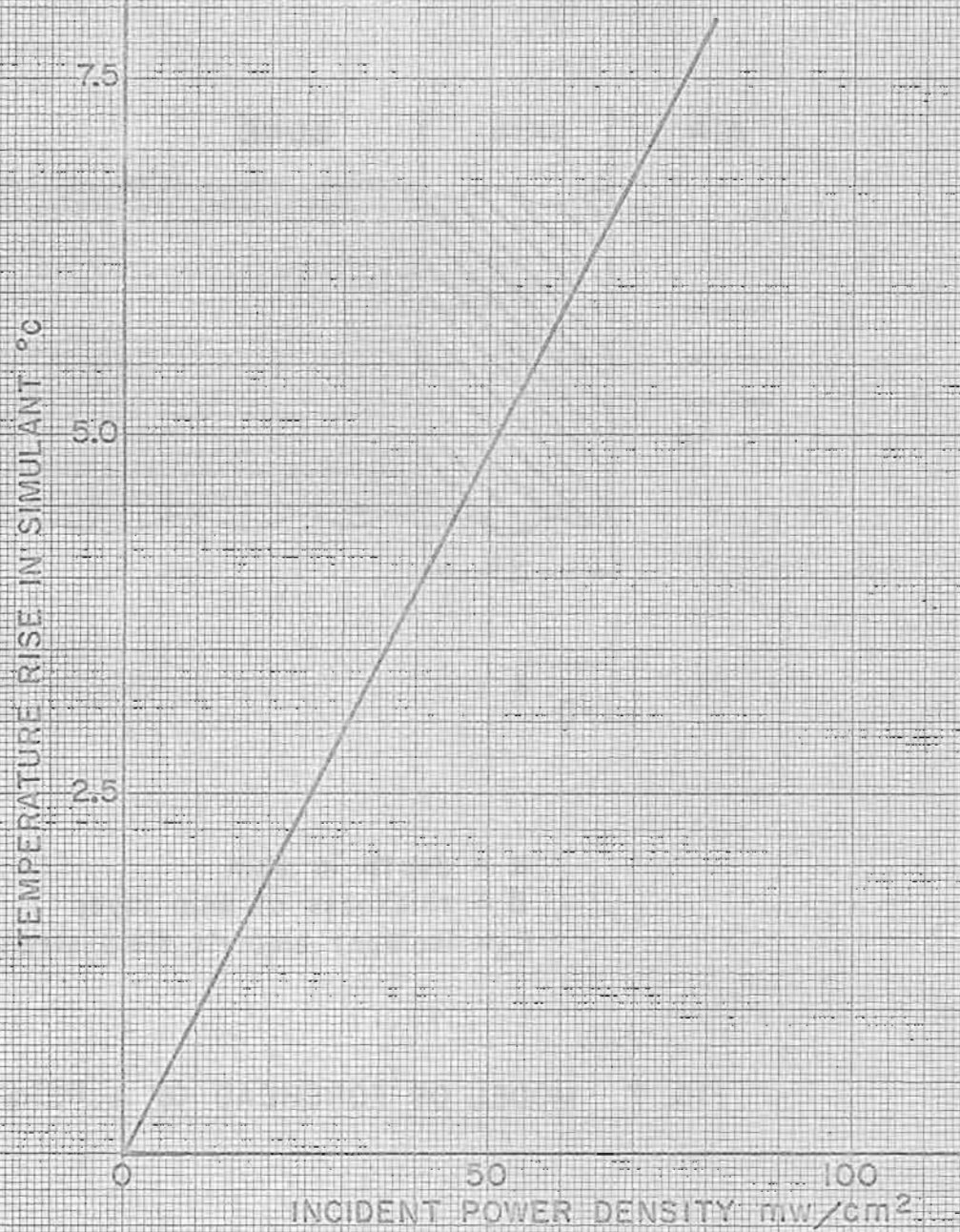
FIG. 6   HEATING OF SKIN SIMULANT BY MICROWAVE ENERGY.
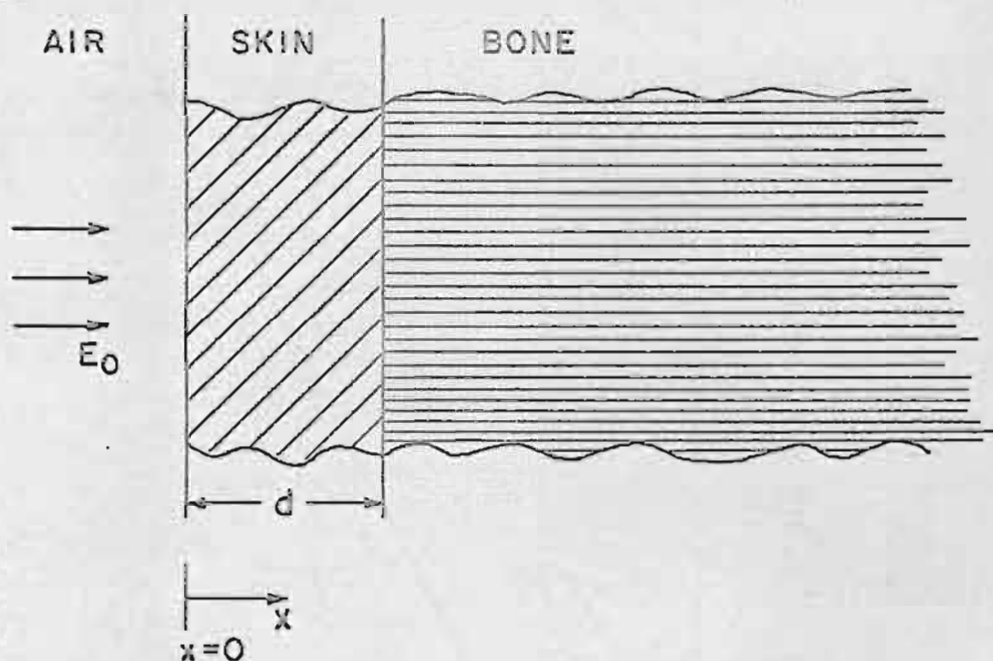
x = depth in skin
d = thickness of skin layer
E_0 = incident electric field strength in air

FIG. 7   MODEL OF FOREHEAD OF A PERSON.

COEFFICIENT OF ABSORPTION (%)

100

50

0

(77%)

(46%)

Dielectric Const.

Conductivity (mmho/cm)

	Skin	Bone
Dielectric Const.	42	8
Conductivity (mmho/cm)	20	2

Frequency : 2880 Mc

Depth of penetration in Skin = 0.87 cm

Wavelength in Skin = 1.6 cm

0   1   2   3

SKIN THICKNESS, d (in cm)
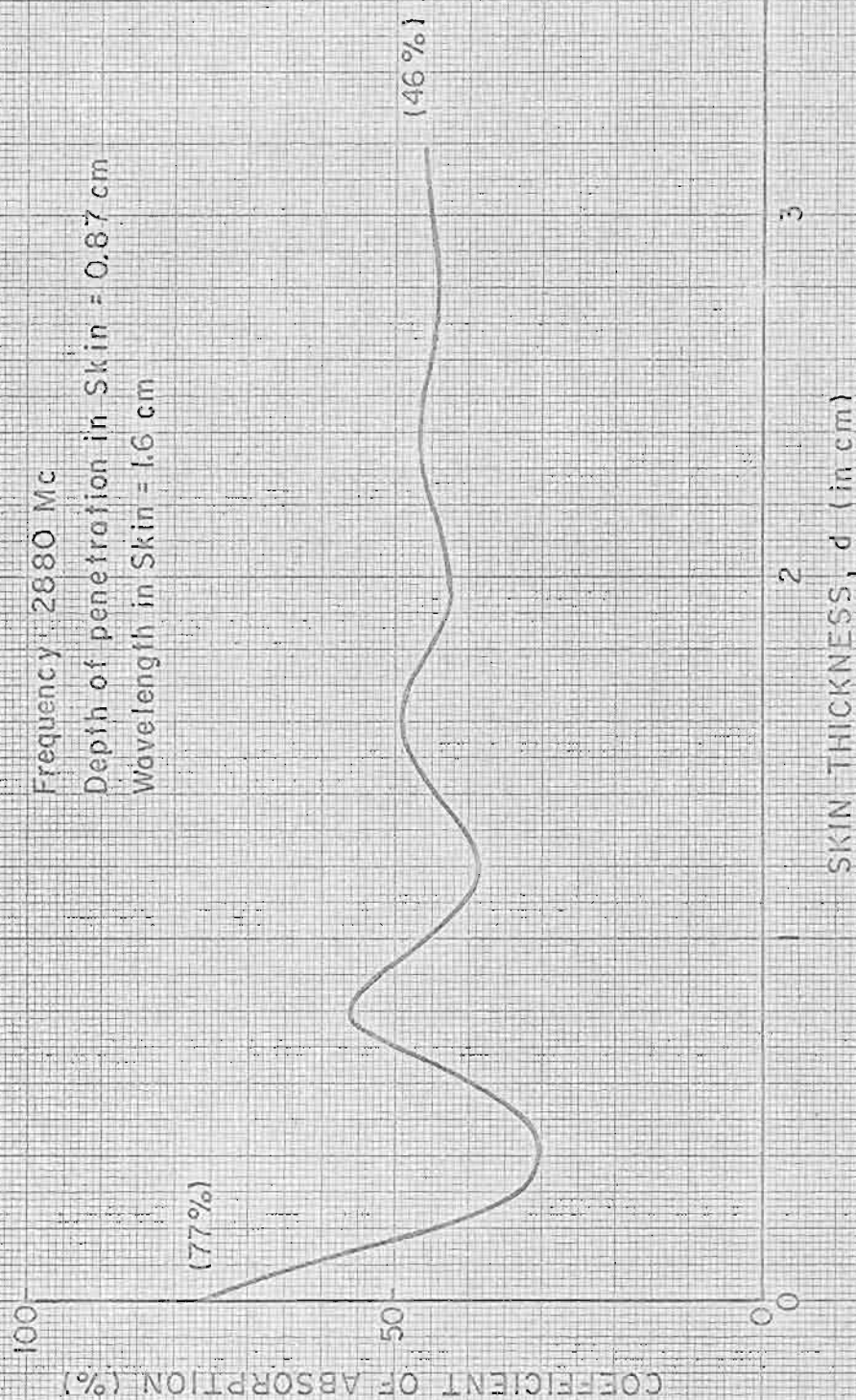
FIG. 8

	Skin	Bone
Dielectric Constant	42	8
Conductivity (mmho/cm)	20	2

Frequency = 2380 mc/s

Depth of penetration in skin = 0.87 cm

Wavelengths in skin = 1.6 cm

Thickness of skin = d cm

Incident electric field
strength in air $(E_0) = \sqrt{0.377}$

FIG. 9   HEAT DEVELOPMENT IN SKIN

DEPTH IN SKIN in cm

HEAT PER UNIT VOLUME (mw)
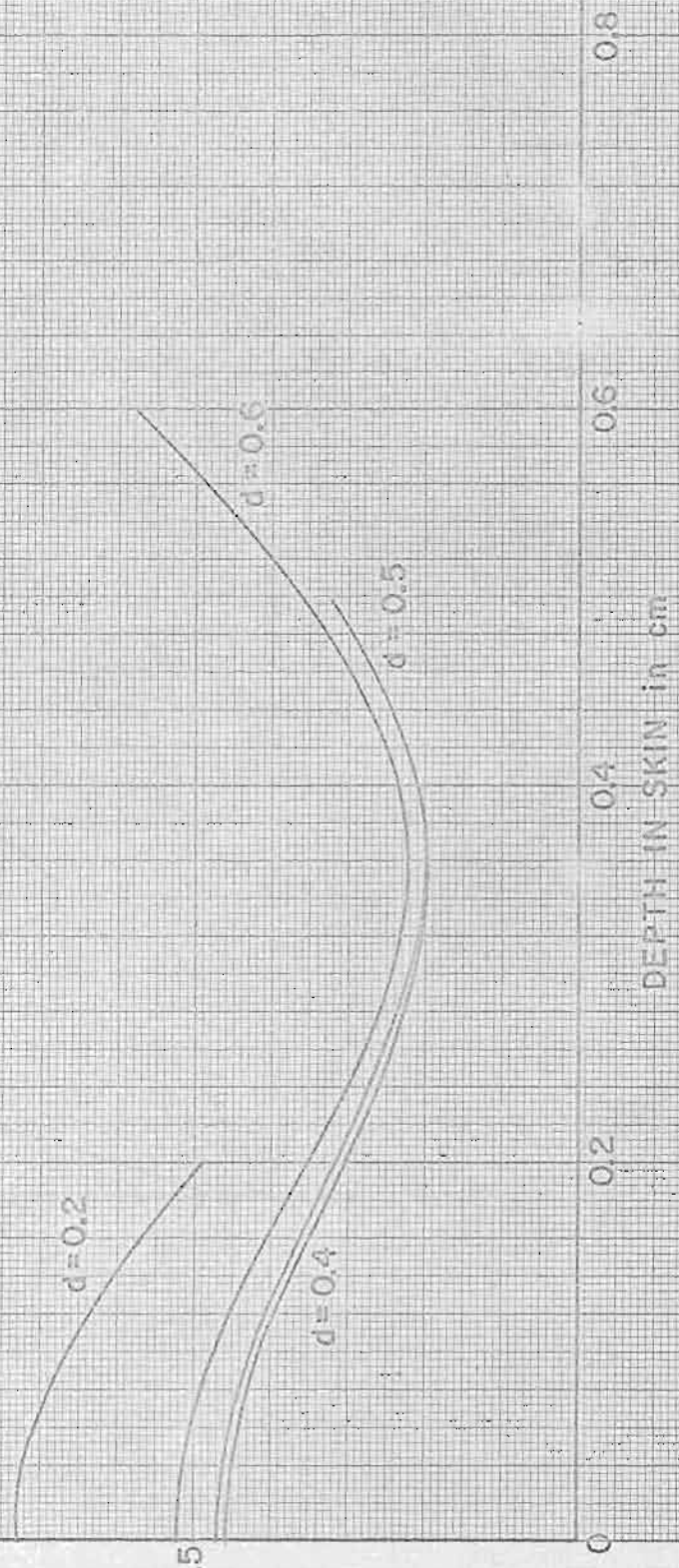
DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
Moore School of Electrical Engineering University of Pennsylvania Philadelphia, Pa.	Unclassified
	2b. GROUP

3. REPORT TITLE

HEATING OF LIVING TISSUES

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final   Jun 1963-Oct 1965

5. AUTHOR(S) (Last name, first name, initial)

Schwan, H. P., Principal Investigator
Anne, A.
Scher, L.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
18 February 1966	30	5

8a. CONTRACT OR GRANT NO. N156-43468	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. BUWEPS Problem Assignment No. 005-AE13-18	NAEC-ACEL-534
c. BUMED Work Unit MR005.13-6003.2	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	Moore School Report No. 66-16

10. AVAILABILITY/LIMITATION NOTICES

U. S. GOVERNMENT AGENCIES MAY OBTAIN COPIES OF THIS REPORT DIRECT FROM DDC. OTHER QUALIFIED DDC USERS SHOULD REQUEST THROUGH THE CHIEF, BUREAU OF NAVAL WEAPONS, WASHINGTON, D. C. 20360.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Aerospace Crew Equipment Laboratory Naval Air Engineering Center Philadelphia, Pa. 19112

13. ABSTRACT

A central forehead area of 4 subjects was exposed to free-field, 10 cm microwave irradiation and the reaction time to onset of warmth sensation measured. Subjective awareness of warmth was found to be only a rough indication of personal hazard, based upon the currently accepted safety standard of 75 mw/cm^2 for 2 min.

DD $^{FORM}_{1\ JAN\ 64}$ 1473

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Microwave hazard						
Temperature sensation						
Absorption of microwave energy						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (corporate author) issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers (either by the originator or by the sponsor), also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through

_____."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through

_____."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through

_____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring (paying for) the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.

DD FORM 1 JAN 64 1473 (BACK)

U.S. NAVAL AIR ENGINEERING CENTER, PHILA., PA.
AEROSPACE CREW EQUIPMENT LABORATORY

HEATING OF LIVING TISSUES; by H. P. Schwan,
A. Anne, and L. Sher, University of Pennsyl-
vania, Moore School of Electrical Engineering,
Final report on contract - 30 pp., 4 Tables,
9 Figs., 18 February 1966.

1. Report NAEC-ACEL-534
2. Problem Assignment No. 005-AE13-18
3. BUMED Work Unit MR005.13-6003.2
4. Contract N156-43468
5. Available to U.S. Government agencies only from DDC.

A central forehead area of 4 subjects was
exposed to free-field, 10 cm microwave irradiation
and the reaction time to onset of warmth sensation
measured. Subjective awareness of warmth was
found to be only a rough indication of personal
hazard, based upon the currently accepted safety
standard of 75 mw/cm^2 for 2 min.