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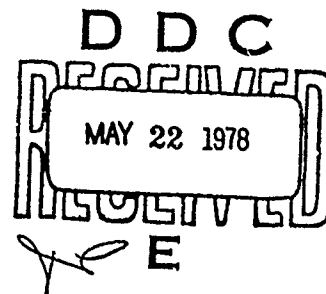
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DEWAR CALORIMETRY TECHNIQUE FOR DETERMINING SPECIFIC ABSORBED POWER OF RODENTS IN RADIOFREQUENCY FIELDS

William D. Hurt, M.S.



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USAF SCHOOL OF AEROSPACE MEDICINE
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NOTICES

This interim report was submitted by personnel of the Radiation Physics Branch, Radiation Sciences Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, Brooks Air Force Base, Texas, under job order 7757-01-43.

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The animals involved in this study were procured, maintained, and used in accordance with the Animal Welfare Act of 1970 and the "Guide for the Care and Use of Laboratory Animals" prepared by the Institute of Laboratory Animal Resources - National Research Council.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A Dewar calorimeter system has been built and demonstrated to be a practical instrument for determining the absorbed power of rodents exposed to radio-frequency fields. Some of the potential pitfalls of this technique have been pointed out and solutions are presented in this paper.		

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DEWAR CALORIMETRY TECHNIQUE FOR DETERMINING SPECIFIC ABSORBED POWER OF RODENTS IN RADIOFREQUENCY FIELDS

INTRODUCTION

Researchers studying biological effects of radiofrequency radiation (RFR) fields often limit the dosimetry to a description of the equipment used and a measured or calculated value for the incident power density. This provides conditions that other investigators could reproduce; however, comparison of dissimilar exposure conditions is not possible unless absorption measurements are also made or theoretically determined. Johnson (1) described the rationale for including this information. Thus, there is general recognition that any description of exposures should include values for the average energy absorbed by a sample configuration. The average energy absorbed by a sample can most easily be calculated from the average temperature of the sample immediately before and after exposure.

This paper describes a method for measuring absorbed energy using a Dewar calorimeter. The method is simple and inexpensive and can be used with many types of samples including whole animals.

MATERIALS

Measuring Equipment

The main component of the Dewar calorimeter was a vacuum flask containing a measured amount of water. The flask was insulated on the bottom and sides with approximately 3 cm of echo foam and sealed with a styrofoam stopper to minimize heat exchange with the environment (Figure 1). The temperature of the water was measured with a thermistor device calibrated by a Precision Data digital multimeter model 3500, Monator Labs scanner model 1200, and Hewlett Packard model 9830 programmable calculator (Figure 2). The program for collecting and analyzing the data was capable of monitoring 6 thermistors simultaneously and was written in BASIC (Appendix A).

1. Johnson, C. C. Recommendations for specifying electromagnetic wave irradiation conditions in bioeffects research. *J Microwave Power* 10:249-250 (1975).



Figure 1. Vacuum flask and thermistor.

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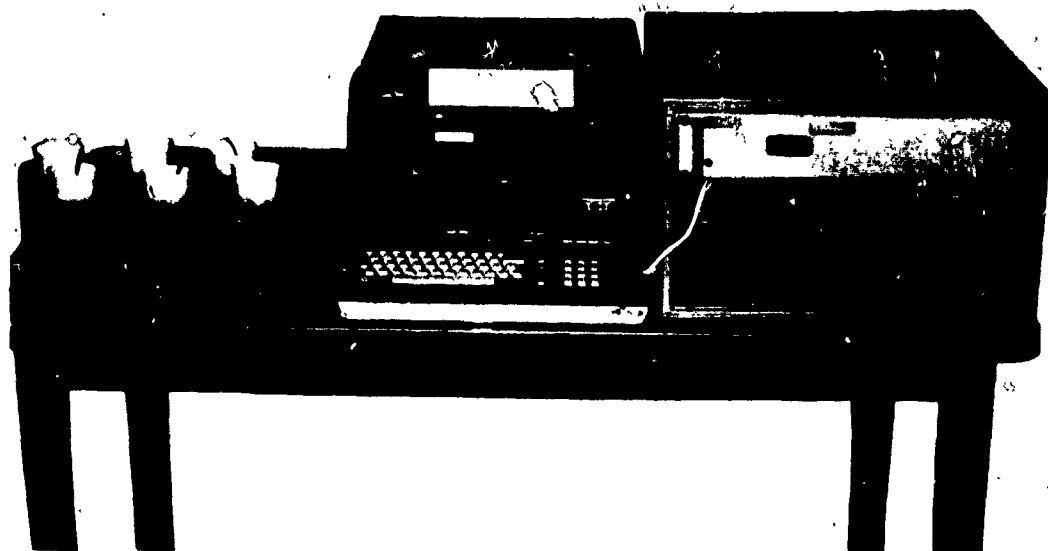


Figure 2. Vacuum flasks, thermistors, programmable calculator, scanner, and multimeter.

RFR Exposure System

Rodents were exposed to 2.6 GHz fields in the far field of a Struthers Electronics Corporation model 110S horn in an anechoic chamber using a Cober generator. An NBS EDM-1B 3-orthogonal dipole probe was used to determine free-field power density at the 18 exposure positions of the animal holder (Figure 3).

METHODS AND PROCEDURES

A simple mathematical relationship was used to calculate the thermal dose from RFR exposure using the initial and final average temperatures of the sample. The average energy absorbed by a sample, E , was computed from the average temperature of the sample immediately

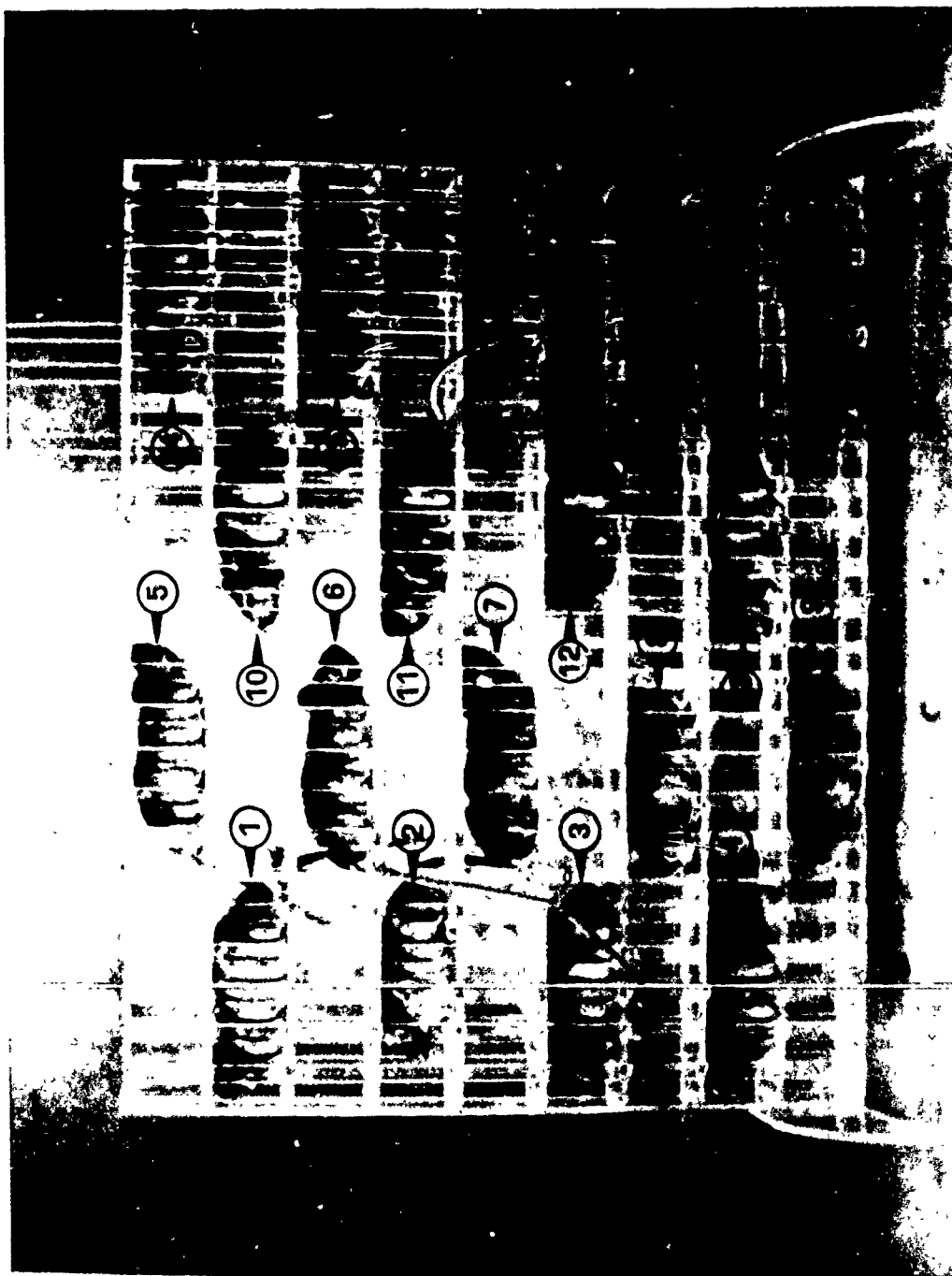


Figure 3. Animal holder.

before, T_b , and after, T_e , the exposure, and the composite specific heat, C , and the mass, M , of the sample. The relationship is:

$$E = MC(T_e - T_b) \quad (1)$$

The average rate of energy absorption can be calculated from E by dividing by the duration of exposure, as long as the temperature change is linearly proportional to the exposure time. Possible artifacts, caused by heat losses as a function of temperature, can be ignored if the temperatures involved remain near ($\pm 4^\circ\text{C}$) ambient. This assumption was confirmed by experimentally determining heat loss rates in mice.

Dewar Calorimeter System

The average temperature of a sample can be measured by Dewar calorimetry. Once the sample is added to the calorimeter, the net energy of the calorimeter system is not changed. The energy change in the sample is exactly balanced by the energy change in the calorimeter. Using equation 1, this energy exchange relationship can be described by:

$$M_s C_s (T_e - T_f) = (Z_d + M_l C_l) (T_f - T_i) \quad (2)$$

where the mass and specific heat of the sample are denoted by M_s and C_s ; and the liquid medium used in the Dewar Flask by M_l and C_l . Z_d is the heat capacity of the Dewar flask. T_i denotes the temperature of the calorimeter system just before the sample is added, and T_f denotes the temperature just after equilibrium is reached. T_e represents the average temperature of the sample immediately after exposure to the radiation.

The parameters in equation 2 were obtained in the following manner: Calorimeter temperatures were measured directly, as were the masses of the various components. Heat capacity of the Dewar flasks (Z_d) was determined when the flasks were filled with 140 ml of distilled water, closely approximating the combination water-animal weight normally used in this study, and was computed from the temperature changes observed when a small 1000-ohm resistor with 25 volts applied across it was submerged in the water for 30 minutes. The specific heat used for water and mice was 1.0 and 0.824 cal/ $^\circ\text{C}$ /gm respectively (2).

2. Hart, J. S. Calorimetric determination of average body temperature of small mammals and its variation with environmental conditions. Can J Zool 29:224-233 (1951).

Absorbed RFR Energy by Mice

To determine the average absorbed energy for mice, the animals were euthanized (by rapid cervical extension) on the day before exposure, thus providing adequate time for the carcasses to equilibrate to ambient conditions by the time of the test. On the day of the experiment, water at approximately 2°C below ambient temperature was weighed out ($\sim 100\text{ g}$) and placed in the calorimeters. While the calorimeters attained temperature equilibrium, the weights of the mice were taken. The 5 carcasses to be exposed were placed in the exposure cage with the remaining 13 positions being occupied by live mice to simulate the actual exposure geometry. A sixth carcass, the control, was placed in the anechoic chamber out of the radiation field. The animal array was placed 150 cm from the front edge of the horn and exposed to a 2.6-GHz field with the transmitter held at a constant output of 280 watts continuous wave (cw). Immediately following a 10-minute exposure, T_i for each calorimeter was obtained and a dead mouse was placed in each calorimeter. Temperatures were recorded every 5 minutes until the calorimeter temperatures stabilized within 0.01°C , usually about 1 hour. This final temperature, T_f , was used with T_i , M_s , C_s , M_l , and C_l , and Z_d in equation 2 to evaluate T_e for each carcass. The T_e for the control animal was taken as the average temperature before irradiation of each of the exposed animals.

RESULTS

Several techniques were used in an attempt to determine the heat capacity of the calorimeters: One was to pour approximately 40 ml of water into a calorimeter which had already come to thermal equilibrium with $\sim 100\text{ g}$ of water; another technique was to pour about 140 ml of water into an empty calorimeter. However, the water cooled during the pouring process; thereby inducing uncertainties in the actual temperature of the water added to the calorimeter. This difficulty was solved by inducing a known amount of energy via the I^2R drop in a resistor submerged in approximately 140 ml of distilled water for a period of 30 minutes. The measurements indicated that the heat capacity of the calorimeters was $6.4 \pm 3.7\text{ cal/}^{\circ}\text{C}$. Table 1 shows the results of the field measurements made in the empty animal container.

Up to three specific absorbed power determinations were made for each of the 18 positions used in the animal container. Results of free field measurements indicate that mice exposed to 2.6 GHz absorb 1.15 W/kg per mW/cm^2 . This factor, applied to the specific absorbed power data, allows a comparison of free field measurements with effective

TABLE 1. RESULTS OF FREE FIELD AND ABSORBED POWER MEASUREMENTS

Holder position No.	Empty holder (mW/cm ²)	Specific absorbed power (W/kg)	Effective power determinations (mW/cm ²)
1	11	22	19
2	14	23	20
3	14	23	20
4	10	16	14
5	12	14	12
6	14	28	24
7	12	22	19
8	14	23	20
9	10	17	14
10	12	19	17
11	14	22	19
12	14	25	22
13	11	14	12
14	11	19	17
15	13	24	21
16	15	20	17
17	14	22	19
18	12	15	13

power density values (Table 1). The average of the 7 inner readings (6, 7, 8, 10, 11, 12, and 13) for free field was only 5% higher than the average of the 11 periphery readings. However, for the specific absorbed power measurements, the 7 inner readings were 12% higher than those on the periphery, probably due to the increase in field resulting from more predominant scatter toward the center than on the edges.

These measurements demonstrate the usefulness of the Dewar calorimetry technique in determining absorbed power from microwave fields. The basic system provides a relatively inexpensive method for determination of the absorbed power in rodents.

APPENDIX A

SPECIFIC ABSORBED POWER PROGRAM

```

10 REM POWER ABSORPTION DETERMINATION VIA CALORIMETRIC TECHNIQUE
20 DIM I[12],S[12],C[12],T[12],W[12]
30 FOR C=1 TO 12
40 READ I[C]
50 NEXT C
60 DATA 0,0,0,0,0,0,0,56.1804,55.635,56.1736,56.2197,56.1699,55.9409
70 FOR D=1 TO 12
80 READ S[D]
90 NEXT D
100 DATA 1,1,1,1,1,1,-0.1847,-0.4087,-0.1849,-0.4402,-0.432,-0.4281
110 FOR F=1 TO 12
120 READ C[F]
130 NEXT F
140 DATA 0,0,0,0,0,0,0,0.0001879,0.0009457,0.0001879,0.0010902,0.0010511,0.0010318
150 M[6]=-10
160 M[5]=-100
170 M[7]=-1000
180 M[3]=-100000
190 PRINT "ENTER 1 TO CALIBRATE THERMISTOR"
200 PRINT "ENTER 2 TO MAKE TEMPERATURE MEASUREMENTS"
210 PRINT "CONT 1020 TO ANALYZE DATA"
220 PRINT
230 INPUT A1
240 IF A1=1 THEN 770
250 DISP "PUT WATER IN CALORIMETER"
260 STOP
270 PRINT "WATER WEIGHTS IN GRAMS";
280 INPUT W[1],W[2],W[3],W[4],W[5],W[6]
290 PRINT
300 PRINT "W1="W[1];"W2="W[2];"W3="W[3];"W4="W[4];"W5="W[5];"W6="W[6]
310 PRINT
320 A2=0
330 A5=6
340 PRINT "INITIAL WATER TEMPERATURE IN DEGREES CENTIGRADE"
350 PRINT
360 GOSUB 900

```

Thermistor
calibration
curve valuesRange constants
for DWMCalorimetry
routineSpecify initial water
temperature routine

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APPENDIX A (CONTINUED)

```

370 WRITE (15,390)T[1],T[2],T[3];
380 WRITE (15,400)T[4],T[5],T[6]
390 FORMAT 'T1=',F7.2,3X,'T2=',F7.2,3X,'T3=',F7.2,3X
400 FORMAT 'T4=',F7.2,3X,'T5=',F7.2,3X,'T6=',F7.2
410 PRINT
420 DISP 'LENGTH OF EXPOSURE IN HOURS =';
430 INPUT A4
440 PRINT 'LENGTH OF EXPOSURE ="A4"HRS"
450 PRINT
460 DISP 'PLACE MICE IN CALORIMETER"
470 STOP
480 PRINT 'MICE WEIGHTS IN GRAMS";
490 INPUT W[7],W[8],W[9],W[10],W[11],W[12]
500 PRINT
510 PRINT 'M1="W[7];"M2="W[8];"M3="W[9];"M4="W[10];"M5="W[11];"M6="W[12]
520 PRINT } Specify water-mouse temperature routine
530 A2=6
540 PRINT 'WATER-MOUSE TEMPERATURE IN DEGREES CENTIGRADE AT 5 MIN. INTERVALS"
550 PRINT
560 WRITE (15,580)
570 PRINT
580 FORMAT 3X,"T1",5X,"T2",5X,"T3",5X,"T4",5X,"T5",5X,"T6"
590 A3=30000
600 GOSUB 900
610 WRITE (15,630)T[7],T[8],T[9],T[10],T[11],T[12]
620 PRINT
630 FORMAT 6F7.2
640 WAIT A3
650 WAIT A3
660 WAIT A3
670 WAIT A3
680 WAIT A3
690 WAIT A3
700 WAIT A3
710 WAIT A3
720 WAIT A3
730 WAIT A3
740 WAIT A3
750 GOTO 600

```

Calorimetry
-routine

Five-minute delay between
water-mouse temperature
readings

APPENDIX A (CONTINUED)

```

760 PRINT
770 A2=A5=0
780 PRINT "THERMISTOR READINGS"
790 PRINT
800 WRITE (15,810)
810 FORMAT 22X,"R1",6X,"R2",6X,"R3",6X,"R4",6X,"R5",6X,"R6"
820 PRINT
830 DISP "TEMPERATURE =" ;
840 INPUT A6
850 PRINT "TEMPERATURE ="A6"C"
860 GOSUB 900
870 WRITE (15,880)T[1],T[2],T[3],T[4],T[5],T[6]
880 FORMAT 18X,6F8.2
890 GOTO 820
900 FOR N=1 TO 6
910 WRITE (1,*)WBYTE65-1.8*N
920 ENTER (4,*)A,B
930 B1=I[N+A5]+S[N+A5]*B*M[A]+C[N+A5]*(B*M[A])^2
940 WAIT 100
950 ENTER (4,*)A,B
960 B2=I[N+A5]+S[N+A5]*B*M[A]+C[N+A5]*(B*M[A])^2
970 IF ABS((B2-B1)/B2) < 0.001 THEN 990
980 GOTO 920
990 T[A2+N]=B2
1000 NEXT N
1010 RETURN
1020 FOR M=1 TO 6
1030 U[M]=((T[M+6]-T[M])*(W[M]+6.4)+T[M+6]*W[M+6]*0.824)/(W[M+6]*0.824)
1040 NEXT M
1050 PRINT
1060 PRINT "INITIAL MOUSE TEMPERATURE IN DEGREES CENTIGRADE"
1070 PRINT
1080 WRITE (15,390)U[1],U[2],U[3],
1090 WRITE (15,400)U[4],U[5],U[6]

```

Thermistor
calibration
routine

Test DVM readings
for stability

Data analysis
routine

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Data analysis
routine

APPENDIX A (CONTINUED)

```
1100 FOR E=2 TO 6
1110 U[E]=(U[E]-U[1])*1.1628/A4
1120 NEXT E
1130 PRINT
1140 PRINT "SPECIFIC ABSORBED POWER IN WATTS PER KILOGRAM"
1150 PRINT
1160 WRITE (15,1170)U[2],U[3],U[4],U[5],U[6]
1170 FORMAT "P2=",F7.3,3X,"P3=",F7.3,3X,"P4=",F7.3,3X,"P5=",F7.3,3X,"P6=",F7.3
1180 PRINT
1190 END
```