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NAMRL TECHNICAL MEMORANDUM 92-3

A COMPUTER PROGRAM TO CALCULATE PLANEWAVE AVERAGE SPECIFIC ABSORPTION RATE IN A PROLATE SPHEROIDAL MODEL

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This report documents a computer program that was developed locally to compute the average specific absorption rate (SAR) for any prolate spheroidal target. It was developed using equation 5.10 from the Radiofrequency Radiation Dosimetry Handbook (4th ed). The program, which is IBM-compatible, is capable of calculating the SAR during microwave radiation exposure for all model sizes ranging from a small mouse to a large human. This procedure removes the restriction of using the Radiofrequency Radiation Dosimetry Handbook, which is limited to only a single or, in some cases, a few sizes of spheroid models.

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SUMMARY PAGE

OVERVIEW

The average specific absorption rate (SAR) is often needed to corroborate a biological finding in a research project or to evaluate human exposure in an occupational or medical setting relative to safety standards. Safety standards (1) promulgate SAR as the metric of maximum permissible exposure. The measurement of SAR in a biological organism exposed to microwave radiation, however, can be a laborious, time-consuming, and sometimes perplexing task. We developed a computer program to compute the average SAR using Equation 5.10 from the Radiofrequency Radiation Dosimetry Handbook, 4th ed.(2). This report describes the computer program, graphical representations of data generated by the program, and methods used to obtain experimental SAR test data.

Acknowledgments

The authors wish to thank Mr. Alfred Thomas for his assistance in many facets of this project: constructing the monkey model bags, preparing the models for experimental testing, and aiding in the calorimetry experiments. In addition, HM2 Lee Buford, Mr. Alfred Thomas, and Mr. Robert Upchurch are gratefully acknowledged for their assistance in construction of the calorimeter, which was utilized to measure the specific absorption rates. Mrs. Peggy Tracy's assistance in correcting and typing the final manuscript is also greatly appreciated.

INTRODUCTION

Laboratory scientists and radiation safety officers in an occupational setting are often required to denote the specific absorption rate (SAR) of a laboratory animal or man exposed to microwave radiation. In the first case, specifying the absorbed dose rate is necessary so that other scientists can replicate an experiment. In the second case, current safety standards (1,3) specify the maximum permissible SAR for occupational as well as general public exposure. Knowledge of the SAR that corresponds to a given field power density found in the occupational or public access areas can be helpful to the safety officer.

The average whole-body SAR can be determined empirically using several calorimetric methods. In the laboratory this usually involves exposing animal carcasses or animal models to microwaves and then measuring thermal changes with temperature probes or whole-body calorimeters (4,5). Recently, methods have been developed to measure SAR in a homogeneous man model in field settings with twin-well calorimeters (6). To determine the SAR, accurate thermal measurements are required that demand careful attention to sources of artifacts. In addition, twin-well calorimetry is a slow process that requires a pair of carcasses or models, which can be costly. These are difficult procedures in a controlled laboratory setting and even more arduous in a noncontrolled field location.

In recent years, a variety of analytical methods have been developed to estimate SAR (7,8). Most of these methods, however, involve solving Maxwell's equations in either integral or differential form. To do so, requires substantial computation on high-speed digital computers and, because of the time required, can be quite expensive.

One helpful approach to both the researcher and radiation safety officer has been the compilations of SAR provided in several editions of the Radiofrequency Radiation Dosimetry Handbook (2,9,10). With the Radiofrequency (RF) Handbook, the safety officer can measure the power density of incident RF or microwave fields in the workplace and then look up the predicted absorption rate for several human targets that vary in size from small children to adults. Even so, the human sizes available in the RF handbook are limited. To provide calculations of SAR, Durney (7) developed an empirical equation to be used with target shapes and sizes that were not available in the RF Handbook. Hurt and Lozano modified this equation and included their results in the 4th edition of the RF Handbook (2). Here, we describe and present (Appendix) a computer program written in the BASIC language that will solve Equation 5.10 from the Radiofrequency Radiation Dosimetry Handbook, 4th ed. (10), which allows the user to calculate SAR for any prolate spheroidal target on a personal desktop IBM-compatible computer.

PROGRAM SPECIFICS

The Radiofrequency Handbook (2) provides average SARs for several animal and human models, but it is limited to only a single or, in some cases, a few sizes of spheroids. For our behavioral studies at this command, we often estimate the average SAR of rhesus monkeys exposed to microwaves with values found in the Handbook. Dosimetry experiments are then conducted to more accurately estimate both average and local SAR in homogeneous models of the rhesus monkey and occasionally monkey carcasses. The Handbook, however, considers only one size of rhesus monkey. To extrapolate this information to other monkey sizes, we selected Equation 5.10 from the Radiofrequency Radiation Dosimetry Handbook, 4th ed. (2) and developed a BASIC language program to solve for average SAR.

$$SAR = \frac{A_1 f^2/f_o^2\,[1+A_4 A_5 (f/f_o-1)^2 (f/f_o)^B]}{1000 f^2/f_o^2 + A_2 (f^2/f_o^2-1)^2}$$

This equation is a modification by Hurt and Lozano (see 2) of the equation by Durney (7). Durney's equation was developed using a combination of antenna theory, circuit theory, and curve fitting to solve for average SAR in the E polarization for spheroids of different sizes. Equation 5.10 was selected because it eliminates the inaccuracies produced by the step functions used by Durney (7) in the transition regions when SAR values are near f_{01} and f_{02}. Also, equation 5.10 specifically includes the frequency-dependent permittivity, which more accurately describes SAR-value variations created by the changes of epsilon (ϵ) with frequency.

The program (SAR.EXE) will run on a standard IBM personal computer or equivalent. It requires only 55 Kbytes of disk space to operate and is available on floppy disk from the authors. Menu selections allow the user to choose either a single frequency or an iteration of frequencies for which to calculate average SAR. Both selections permit the user to store the data in an ASCII file and to obtain a hard copy of the data.

Once the data are written to the ASCII file, graphical and statistical analysis can be performed. Sigma Plot 4.1 (11) was used to construct figures 1, 2, 3, and 4 using data obtained from the SAR.EXE program. Figure 1 compares the results from a 3-liter plastic bottle filled with a saline solution (0.9% Sodium Chloride Irrigation, USP) and a bag monkey model using the appropriate phantom muscle material (12) for the transmitted frequency (5.62 GHz) to the actual curve generated from the data obtained from the SAR.EXE program for the size of the bag monkey model being used. Figures 2, 3, and 4 replicate the graphs shown in the Radiofrequency Handbook (2) for an average man, medium rat, and medium mouse. The data points for graphs 2, 3, and 4 were obtained from the SAR program using the sizes given in the Dosimetry Handbook that corresponded to each subject.

EXPERIMENTAL RESULTS

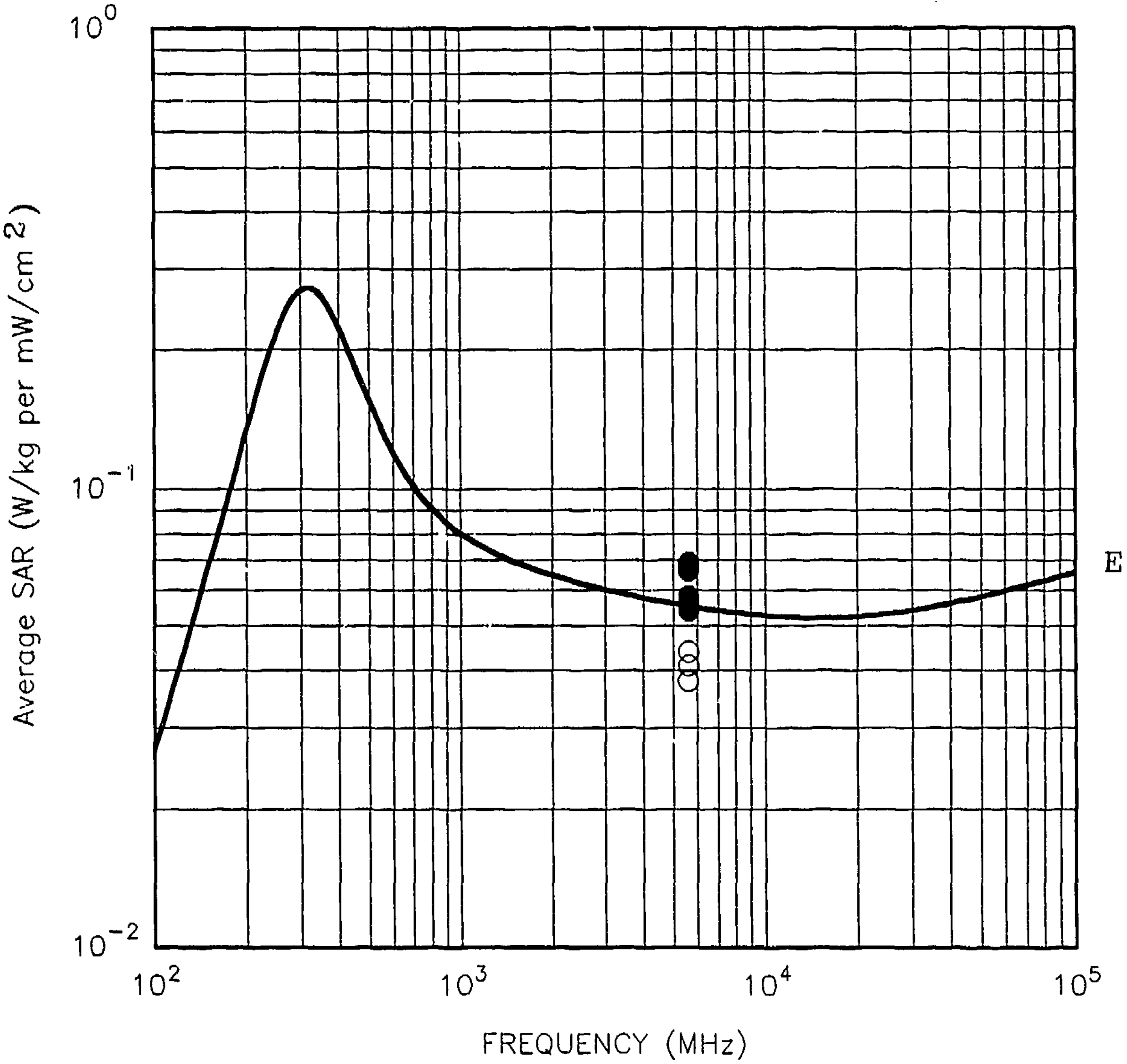
Pulsed microwave energy was generated by an AN/FPS-26A radar operating at 5.62 GHz. The average power output was adjusted to produce an average power density measurement of 108 mW/cm^2 in the far-field. To obtain data points for the 3-liter bottle and the bag monkey model, targets located in the far-field, and a sham placed away from the microwave field, were exposed for a period of 5-min. We constructed a twin-well calorimeter (13) to determine whole-body SAR after the primary design of Hunt and Philips (4). The absorption rate (W/kg) for each model was calculated using an integration of the calorimeter output (area under the curve using Simpson's Rule), model weight, specific heat rating, length of exposure, and area to length of exposure ratio of the twin-well calorimeter calibration. The SARs for the monkey bag model were determined experimentally using twin-well calorimetry and were compared to the SAR values calculated by the SAR-EXE program (0.053 W/kg) as shown in Fig 1.

PROGRAM ADVANTAGES

At this laboratory, the types of tissue simulating materials and the sizes of the models used to determine the SAR values can vary considerably from one model to the next. The primary advantage of the SAR.EXE program is that SARs for model sizes that are not available in the Radiofrequency Handbook can be quickly calculated. Whether SAR values are needed in the laboratory or in the workplace, they are calculated readily for a model of any dimension ranging from a small rat to a large human. A second advantage is that the program is stand-alone; it requires no other program or file to execute. It is a relatively small program and requires little space to operate (55 Kbytes) and can be run from either a floppy or hard disk. A third advantage is programming maintenance. The program is written in MicroSoft QuickBASIC Professional Development System version 7.1 (Appendix) allowing any changes to the program to be made by a qualified QuickBASIC computer programmer. The program is free of excessive code thereby keeping the BASIC program compact. The only disadvantage is a small sacrifice in accuracy of 10-15% of Equation 5.10, but this is offset by the advantage of calculating average SAR quickly without having to conduct extensive empirical experiments or solve Maxwell's equations on a mainframe computer.

CONCLUSIONS

The empirical Equation 5.10 in the Radiofrequency Radiation Dosimetry Handbook is a relatively accurate method of calculating average SARs. A program to calculate SAR values for model sizes that are not found in the Radiofrequency Handbook is a useful tool for estimating these values quickly and with reliable accuracy conserving valuable time and money. We have utilized the SAR.EXE program at the Naval Aerospace Medical Research Laboratory and believe the addition of this program will be a beneficial aid for estimating SAR values in both laboratory and workplace environments.

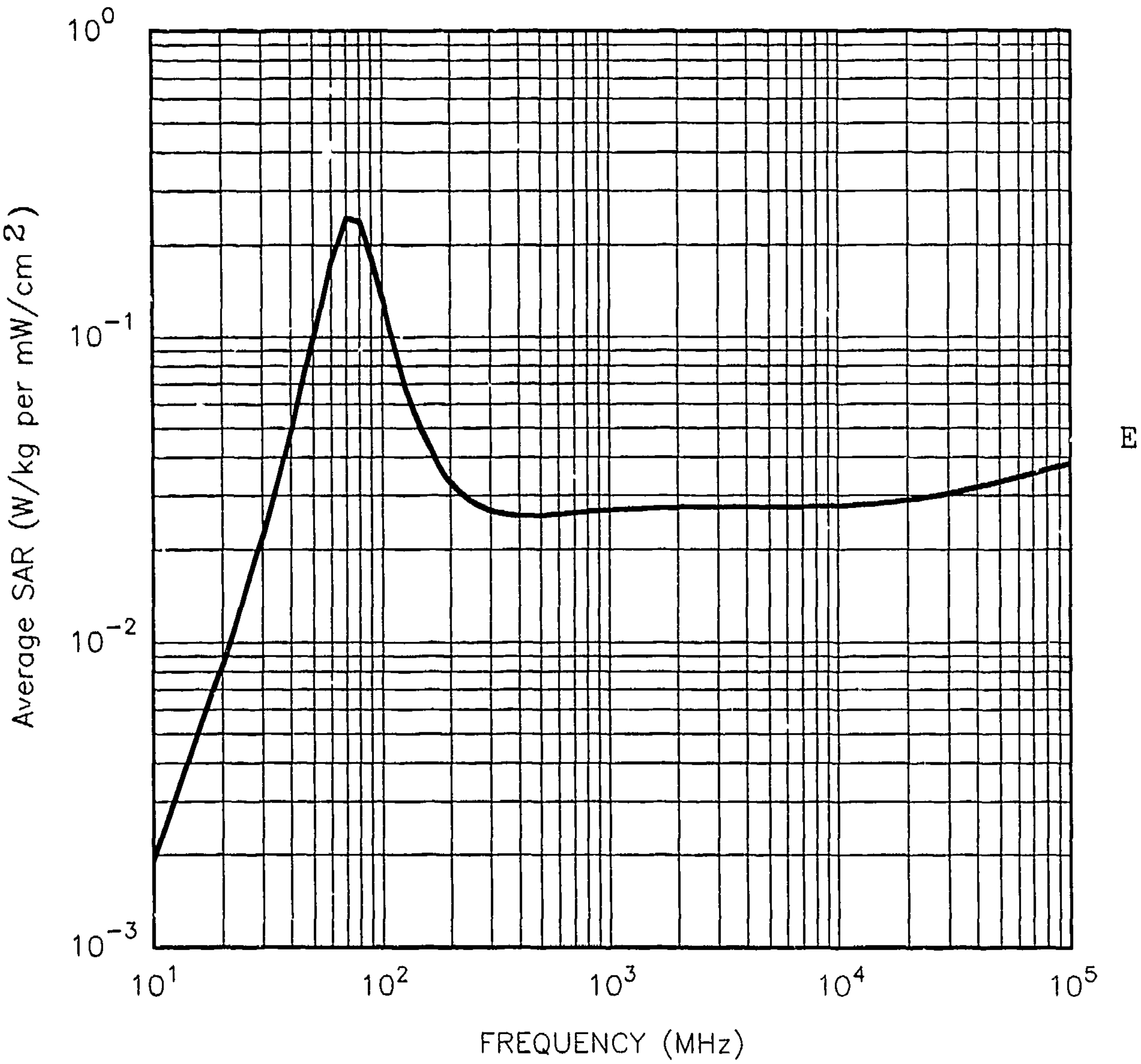


Calculated planewave average SAR in a prolate spheroidal model of a sitting rhesus monkey.

● Phantom muscle material in 5.2 kg monkey model
a = .23m, b = .067m

○ 3 liter bottle filled with saline solution
a = .135m, b = .12m

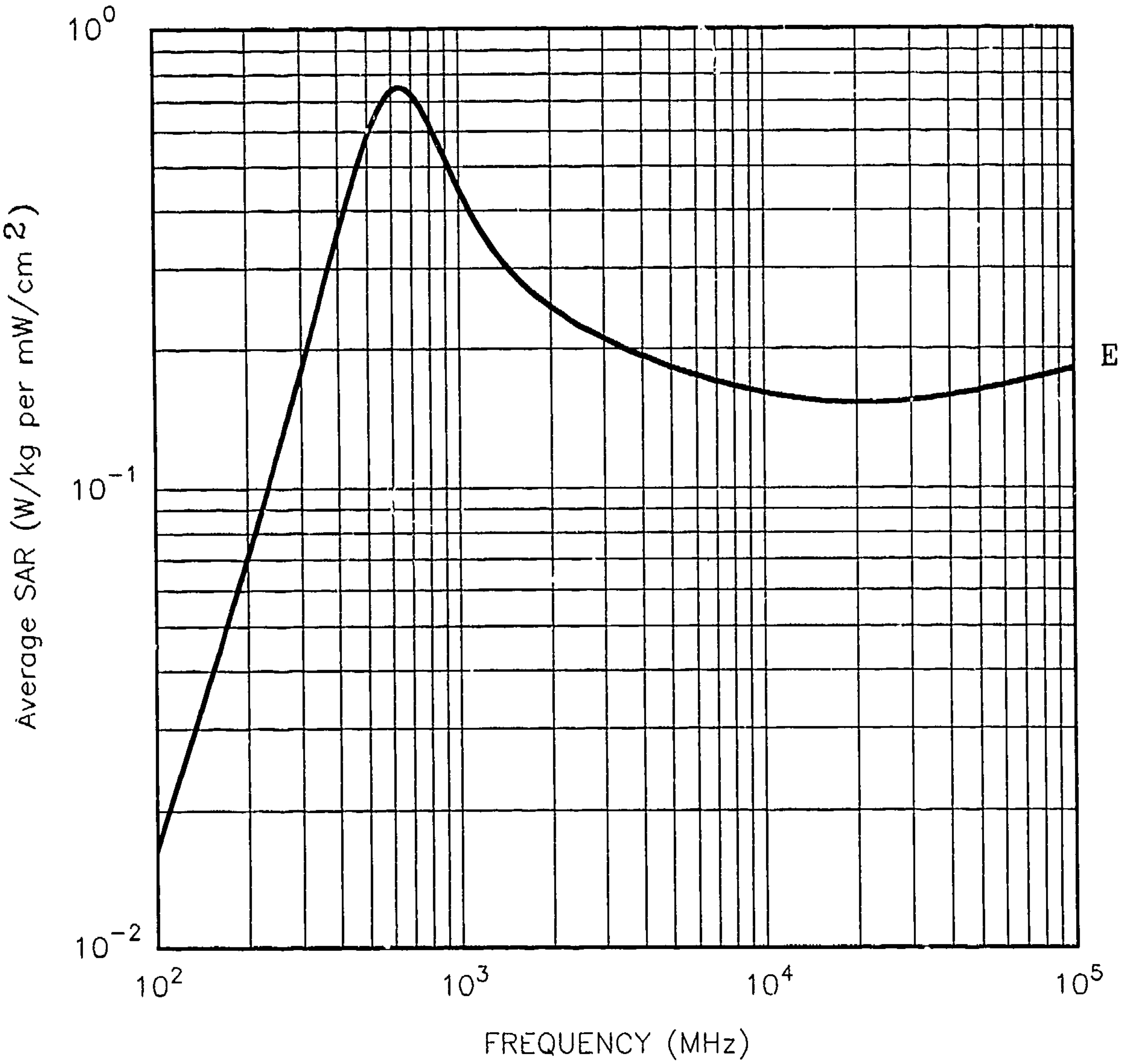
Figure 1.



Calculated planewave average SAR in a prolate spheroidal model of an average man.

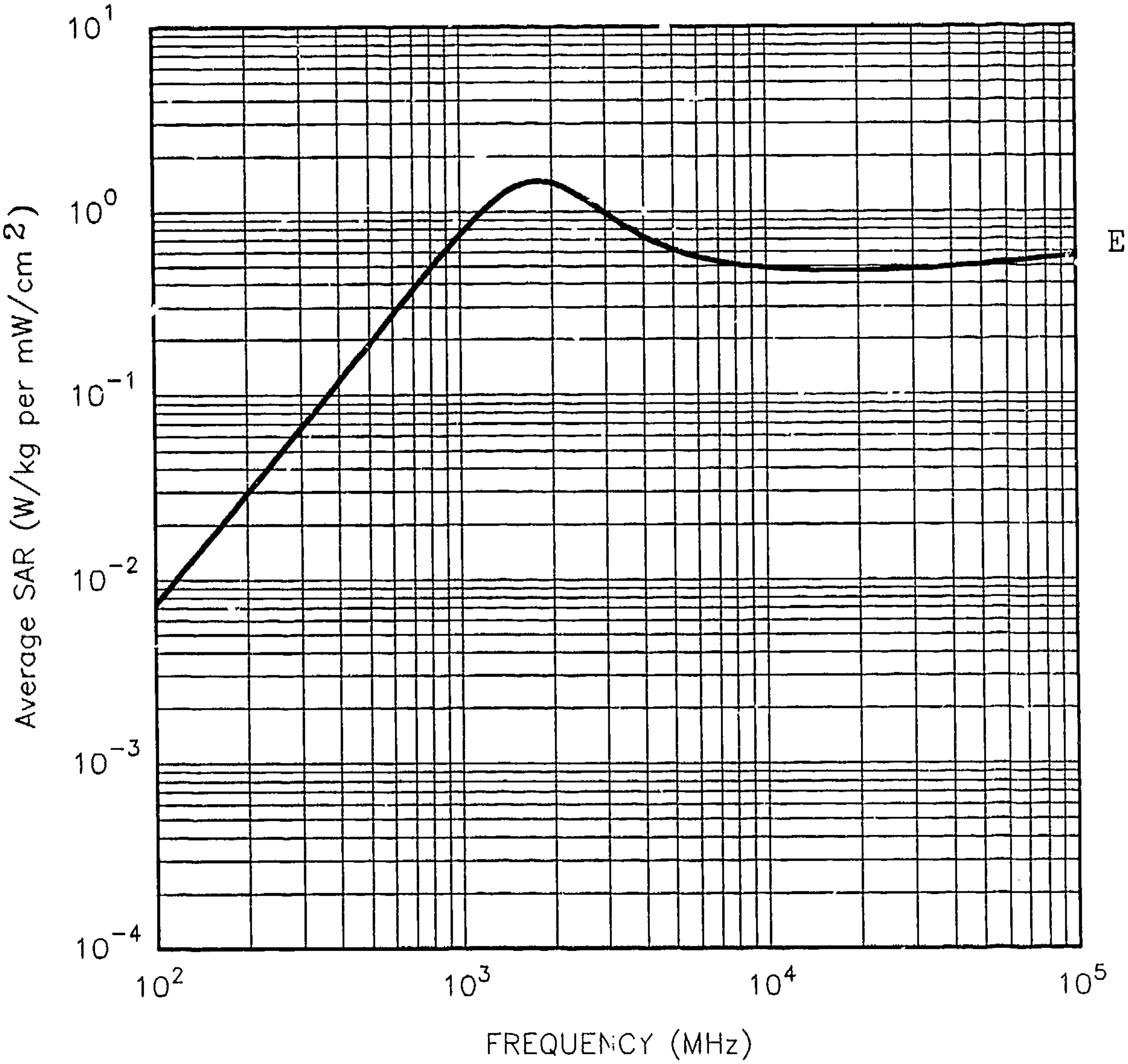
a = 0.875m, b = 0.138m

Figure 2.



Calculated planewave average SAR in a prolate spheroidal model of a medium rat.
a = 0.1m, b = 0.0276m

Figure 3.



Calculated planewave average SAR in a prolate spheroidal model of a medium mouse.
a = 0.035m, b = 0.0117m

Figure 4.

REFERENCES

1. American National Standards Institute, *American National Standard Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 300 KHz to 100 GHz*, ANSI C95.1-1991, The Institute of Electrical and Electronic Engineers, Inc., New York, NY, 1991.

2. Durney, C.H., Massoudi, H., and Iskander, M.F., *Radiofrequency Radiation Dosimetry Handbook (4th ed)*, USAFSAM-TR-85-73, USAF School of Aerospace Medicine, Aerospace Medical Division, Brooks Air Force Base, TX., 1986.

3. National Council on Radiation Protection and Measurements, *Biological Effects Exposure Criteria for Radiofrequency Electromagnetic Fields*, NCRP Report No. 91, National Council on Radiation Protection and Measurements, Bethesda, MD, 1987.

4. Hunt, E.L. and Phillips, R.D., "Absolute Physical Dosimetry for Whole Body Animal Experiments." Joint U.S. Army/Georgia Institute of Technology Microwave Dosimetry Workshop Digest of Papers, Walter Reed Army Institute of Research, Washington DC, 1972.

5. Olsen, R.G. and Griner, T.A., "Electromagnetic Dosimetry in a Sitting Rhesus Model at 225 MHz." *Bioelectromagnetics*, Vol. 3, pp. 385-389, 1982.

6. Olsen, R.G. and Griner, T.A., "Outdoor Measurement of SAR in a Full-sized Human Model Exposed to 29.9 MHz in the Near Field." *Bioelectromagnetics*, Vol. 10, pp. 161-171, 1989.

7. Durney, C.H., Iskander, M.F., Massoudi, H., and Johnson, C.C., "An Empirical Formula for Broad-Band SAR Calculations of Prolate Spheroidal Models of Humans and Animals." *IEEE Transactions on Microwave Theory and Techniques*, Vol. MTT-27, No. 8, August 1979.

8. Spiegel, R.J., "A Review of Numerical Models for Predicting the Energy Deposition and Resultant Thermal Response of Humans Exposed to Electromagnetic Fields." *IEEE Transactions on Microwave Theory and Techniques*, Vol. 32, No. 8, pp. 730-746, 1984.

9. Durney, C.H., Johnson, C.C., Barber, P.W., Massoudi, H., Iskander, M.F., Lords, J.L., Ryser, D.K., Allen, S.J., and Mitchell J.C., *Radiofrequency Radiation Dosimetry Handbook (2nd ed.)*, SAM TR-78-22, USAF School of Aerospace Medicine, Aerospace Medical Division, Brooks Air Force Base, TX., 1978.

10. Durney, C.H., Iskander, M.F., Massoudi, H., Allen, S.J., and Mitchell, J.C., *Radiofrequency Radiation Dosimetry Handbook (3rd ed.)*, SAM-TR-80-32, USAF School of Aerospace Medicine, Aerospace Medical Division, Brooks Air Force Base, TX., 1980.

11. Norby, J., Rubenstein, S., Tuerke, T., Farmer, C.S., and Bennington, J., *SigmaPlot: Scientific Graph Systems Version 4.1*, Jandel Scientific, San Rafeal, CA, 1992.

12. Cheung, A.Y. and Koopman, D.W., "Experimental Development of Simulated Biomaterials for Dosimetry Studies of Hazardous Microwave Radiation." *IEEE Transactions on Biomedical Engineering*, MTT-24, pp. 669-673, 1976.

13. D'Andrea, J.A, Emmerson, R.Y., Bailey, C.M., Olsen, R.G., and Gandhi, O.P., "Microwave Radiation Absorption in the Rat: Frequency-Dependent SAR Distribution in Body and Tail." *Bioelectromagnetics*, Vol. 6, pp. 199-206, 1985.

Other Related NAMRL Publications

None are applicable.

APPENDIX

BASIC PROGRAMMING CODE FOR THE SAR.EXE PROGRAM

```
  ' SAR.BAS
  ' This program is written in MicroSoft QuickBasic Ver. 7.1

  ' Source Code by: Donald Hatcher and Dr. John D'Andrea
  ' Date: March 27, 1991

  ' This program calculates the SAR (W/Kg) for a given size
  ' target at a given frequency.  If desired, the program will
    calculate the SAR's for a range of frequencies.
  ' Equation 5.10 on page 5.7 of the RadioFrequency Radiation Dosimetry
  ' Handbook is used to perform calculations.

  DECLARE SUB Menu (selection!)
  DECLARE SUB TargetSize (a!, b!)
  DECLARE SUB Frequency (f!)
  DECLARE SUB PrintOptions (file$, printout$)

  DECLARE FUNCTION ResonantFrequency! (a!, b!, PI!, EX!)
  DECLARE FUNCTION FrequencySquared! (f!)
  DECLARE FUNCTION ResonantFrequencySquared! (FO!)
  DECLARE FUNCTION Eq59! (EDPrime20!, EDPrimeF!, EPrimeF!, EPrime20!)
  DECLARE FUNCTION Eq56! (a!, b!)
  DECLARE FUNCTION Eq58! (a!, b!)
  DECLARE FUNCTION Eq510! (A1!, A2!, A4!, A5!, F2!, FO2!, PI!, a!, b!, FO!, f!)
  DECLARE FUNCTION Eq424! (Conductivity!, PI!, f!)
  DECLARE FUNCTION Eq452! (f!)
  DECLARE FUNCTION Eq453! (f!)
  DECLARE FUNCTION Eq55! (a!, b!)

  CLS
  CLEAR , , 4000
  COLOR 15, 4

  PI = 3.14159264#
  EX = 1 / 2
  EX2 = 1 / 4

  ' The following values are for 20 GHz
  EPrime20 = 27.8
  EDPrime20 = 21.58
  CONDUCTIVITY20 = 24
  selection = 0

WHILE selection <> 3
  CALL Menu(selection)
  SELECT CASE (selection)
      CASE 1
          CALL PrintOptions(file$, printout$)
          CALL Frequency(f)
          interval = 1
      CASE 2
          CLS
          CALL PrintOptions(file$, printout$)
          PRINT
          INPUT " Enter starting frequency (MHz)..: ", f
          INPUT " Enter ending frequency (MHz)....: ", endf
          INPUT " Enter frequency intervals (MHz).: ", interval
          PRINT
          endf = endf * 1000000
          f = f * 1000000
      CASE 3
          GOSUB Quit
  END SELECT
```

```
    CALL TargetSize(a, b)

    DO

        ' Calculate Resonant Frequency
        FO = ResonantFrequency(a, b, PI, EX)

        F2 = FrequencySquared(f)
        FO2 = ResonantFrequencySquared(FO)

        EPrimeF = Eq452(f)
        Conductivity = Eq453(f)
        EDPrimeF = Eq424(Conductivity, PI, f)

        A1 = Eq55(a, b)
        A2 = Eq56(a, b)
        A4 = Eq58(a, b)
        A5 = Eq59(EDPrime20, EDPrimeF, EPrimeF, EPrime20)

        SAR = Eq510(A1, A2, A4, A5, F2, FO2, PI, a, b, FO, f)

        PRINT
        PRINT USING " SAR = ##.##### for target sizes "; SAR;
        PRINT USING "of a = #.##### and b = #.#####"; a; b;
        PRINT USING " at ###### MHz"; f / 1000000
        PRINT

        IF file$ <> "XXXXXXXX.XXX" THEN
            WRITE #1, f, SAR
        END IF

        IF UCASE$(printout$) = "Y" THEN
            LPRINT USING "######               ##.######"; f / 1000000; SAR;
            LPRINT USING "      ##.#####     ##.#####"; a; b
        END IF

        f = f + interval * 1000000      ' Increment to next frequency

    LOOP UNTIL f >= endf

    PRINT
    PRINT " Press Any Key To Continue...";
    q$ = INPUT$(1)
    selection = 0

  WEND

Quit:
     CLOSE
     COLOR 7, 0
     CLS
     END

*****************************************************************************************************
FUNCTION Eq424 (Conductivity, PI, f) STATIC

' Calculate E'' (Double Prime) using formula 4.24 where :
```

$$\epsilon^{\prime\prime}=\sigma/\omega e_o$$

```
    Eq424 = Conductivity / (2 * PI * f * 8.85E-12)

END FUNCTION

*****************************************************************************************************
```

```
FUNCTION Eq452 (f) STATIC

' The following calculations solve for e' using formula given on page
' 4.52
```

$$\epsilon' = \frac{2340000}{1+(f/78)^2} + \frac{62100}{1+(f/76X10^3)^2} + \frac{1970}{1+(f/2.6X10^6)^2} + \frac{30.8}{1+(f/340X10^6)^2} + \frac{41.3}{1+(f/23X10^9)^2} + 4.3$$

```
    K = 2340000! / (1 + (f / 78) ^ 2)     ' Calculate E' for frequency
    H = 62100! / (1 + (f / 76000!) ^ 2)
    C = 1970 / (1 + (f / 2600000!) ^ 2)
    D = 30.8 / (1 + (f / 3.4E+08) ^ 2)
    P = 41.3 / (1 + (f / 2.3E+10) ^ 2)
    G = 4.3
    Eq452 = K + H + C + D + P + G

END FUNCTION
```

****

```
FUNCTION Eq453 (f) STATIC

' Calculate Conductivity for frequency using formula given on page 4.53
```

$$\sigma = \frac{1.67X10^{-6}f^2}{1+(f/78)^2} + \frac{4.54X10^{-11}f^2}{1+(f/76X10^3)^2} + \frac{4.21X10^{-14}f^2}{1+(f/2.6X10^6)^2} +$$

$$\frac{5.04X10^{-18}f^2}{1+(f/340X10^6)^2} + \frac{9.99X10^{-20}f^2}{1+(f/23X10^9)^2} + 0.106$$

```
    K = ((1.67E-06) * f ^ 2) / (1 + (f / 78) ^ 2)
    H = ((4.54E-11) * f ^ 2) / (1 + (f / 76000!) ^ 2)
    C = ((4.21E-14) * f ^ 2) / (1 + (f / 2600000!) ^ 2)
    D = ((5.04E-18) * f ^ 2) / (1 + (f / 3.4E+08) ^ 2)
    P = ((9.99E-20) * f ^ 2) / (1 + (f / 2.3E+10) ^ 2)
    G = .106

    Eq453 = K + H + C + D + P + G

END FUNCTION
```

****

```
FUNCTION Eq510 (A1, A2, A4, A5, F2, FO2, PI, a, b, FO, f) STATIC

' Solve for SAR using equation 5.10
```

$$SAR=\frac{A_1 f^2/f_o^2[1+A_4A_5(f/f_o-1)^2(f/f_o)^B]}{1000f^2/f_o^2+A_2(f^2/f_o^2-1)^2}$$

```
    AA = A1 * F2 / FO2
    MT = (4 / 3) * PI * (a) * (b ^ 2)
    UT1 = -.16
    UT2 = (1.128 * (LOG(MT) / 2.302585) ^ 2)
    UT3 = (.0438 * (LOG(MT) / 2.302585) ^ 4)
    UT4 = (51.4 * b)
    UT5 = (271 * b ^ 2)
    UT6 = (8.902001 * a)
    UT7 = (9 * a ^ 2)
    UT = UT1 + UT2 - UT3 + UT4 - UT5 - UT6 + UT7
    BX = FO / f
    BT# = UT ^ BX
    BT# = BT# - 1

    XX = 1 + (A4) * (A5) * (f / FO - 1) ^ 2 * (f / FO) ^ BT#
    EE = 1000 * F2 / FO2
    FF = A2 * ((F2 / FO2 - 1) ^ 2)
    JJ = EE + FF

    Eq510 = AA * XX / JJ

END FUNCTION

*************************************************************************************************

FUNCTION Eq55 (a, b) STATIC
```

$$A_1=-0.994-10.690a+0.172a/b+0.739a^{-1}+5.660a/b^2$$

```
    Eq55A = -.994 - (10.69 * a) + (.172 * (a / b))
    Eq55B = (.739 * a ^ -1) + (5.66 * (a / b ^ 2))
    Eq55 = Eq55A + Eq55B

END FUNCTION

*************************************************************************************************
FUNCTION Eq56 (a, b) STATIC

' Solve for A2 using equation 5.6
```

$$A_2=-0.914+41.400a+399.170a/b-1.190a^{-1}-2.141a/b^2$$

```
  Eq56A = -.914 + (41.4 * a)
  Eq56B = (399.17 * (a / b)) - (1.19 * (a ^ -1)) - (2.141 * (a / b ^ 2))
  Eq56 = Eq56A + Eq56B

END FUNCTION

*************************************************************************************************
```

```
FUNCTION Eq58 (a, b) STATIC

' Solve for A4 using equation 5.8
```

$$A_4=0.335a+0.075a/b-0.804a^2-0.0075(a/b)^2+0.640a^3$$

```
    Eq58A = (.335 * a)
    Eq58B = (.075 * (a / b)) - (.804 * a ^ 2) - (.0075 * (a / b) ^ 2)
    Eq58C = (.64 * a ^ 3)
    Eq58 = Eq58A + Eq58B + Eq58C

END FUNCTION
*****************************************************************************************************************
FUNCTION Eq59 (EDPrime20, EDPrimeF, EPrimeF, EPrime20) STATIC

' Solve A5 using equation 5.9 on page 5.6
```

$$A_5=|\epsilon/\epsilon_{20}|^{-1/4}$$

```
    A51 = ABS(EDPrime20 * -(EDPrimeF))
    A52 = EDPrime20 * EPrimeF
    A53 = EPrime20 * -(EDPrimeF)
    A54 = EPrime20 * EPrimeF
    A56 = A54 + A51
    A57 = A52 + A53
    A58 = (EPrime20) ^ 2
    A59 = (EDPrime20) ^ 2
    A510 = A56 / (A58 + A59)
    A511 = A57 / (A58 + A59)
    A512 = A510 ^ 2
    A513 = A511 ^ 2

    Eq59 = (SQR(A512 + A513)) ^ -(1 / 4)

END FUNCTION

*****************************************************************************************************************

SUB Frequency (f) STATIC

    PRINT
    INPUT " Input desired frequency (MHz): ", f
    f = f * 1000000

END SUB

*****************************************************************************************************************

FUNCTION FrequencySquared (f) STATIC

    FrequencySquared = f ^ 2

END FUNCTION

*****************************************************************************************************************
```

```
SUB Menu (selection) STATIC

        CLS
        LOCATE 3, 26
        PRINT "SAR Calculation Program"
        LOCATE 5, 17: PRINT STRING$(40, 240)
        LOCATE 7, 17
        PRINT "1............ Single Frequency"
        LOCATE 9, 17
        PRINT "2............ Iterations of Frequencies"
        LOCATE 11, 17
        PRINT "3............ Exit SAR Program"
        LOCATE 13, 17: PRINT STRING$(40, 240)
    WHILE selection < 1 OR selection > 3
        LOCATE 15, 26
        PRINT "Make selection (1-3): "; : COLOR 31, 4: PRINT "■"
        COLOR 15, 4
        selection = VAL(INKEY$)
    WEND

END SUB

**********************************************************************************************************

SUB PrintOptions (file$, printout$) STATIC

    CLS
    PRINT
    INPUT " Do you want to store data to a file (Y/N)....: ", response$
    IF UCASE$(response$) = "Y" THEN
        PRINT
        INPUT " Enter file name: ", file$
        OPEN file$ FOR OUTPUT AS #1
    ELSE file$ = "XXXXXXXX.XXX"
    END IF
    PRINT
    INPUT " Do you want to send output to printer (Y/N)..: ", printout$
    IF UCASE$(printout$) = "Y" THEN
        LPRINT
        LPRINT " FREQUENCY (MHz)        SAR           TARGET  SIZES  "
        LPRINT "                                      a               b"
        LPRINT "-------------------------------------------------------------"
        LPRINT
    END IF
END SUB

**********************************************************************************************************

FUNCTION ResonantFrequency (a, b, PI, EX) STATIC
```

$$f_o(Hz)=2.75X10^8[8a^2+\pi^2(a^2+b^2)]^{-1/2}$$

```
   ResonantFrequency = 2.75E+08 * ((8 * a ^ 2 + PI ^ 2 * (a ^ 2 + b ^ 2)) ^ -EX)

END FUNCTION

**********************************************************************************************************
FUNCTION ResonantFrequencySquared (FO)

    ResonantFrequencySquared = FO ^ 2

END FUNCTION

**********************************************************************************************************
```

```
SUB TargetSize (a, b) STATIC

    PRINT
    PRINT " a = 1/2 the height of the target in meters."
    PRINT " b = 1/2 the width of the target in meters (Less than .187)."
    PRINT
    a = 0
    b = 0
    bad = 0
    DO
        LOCATE CSRLIN, 1: PRINT " Enter value for a:    "
        LOCATE CSRLIN - 1, 21: LINE INPUT "", a$
        bad = INSTR("/<>?~\;:][](=-_+)(*&^%$#@!,", a$)
        IF bad > 0 THEN a$ = "0"
        a = VAL(a$)
        LOCATE CSRLIN - 1, 1
        IF a <= 0 THEN
            LOCATE CSRLIN, 21: PRINT "*** Incorrect Entry ***"
            FOR repeat = 1 TO 3
                SOUND 1650, .2
                FOR delay = 1 TO 1000: NEXT delay
            NEXT repeat
            SLEEP 2
            LOCATE CSRLIN - 1
            LOCATE CSRLIN, 18: PRINT STRING$(30, 255)
            LOCATE CSRLIN - 1
        END IF
        LOOP UNTIL a > 0
    PRINT
    bad = 0

    DO
        LOCATE CSRLIN, 1: PRINT " Enter value for b:    "
        LOCATE CSRLIN - 1, 21: LINE INPUT "", b$

        bad = INSTR("/<>?~\;:][](=-_+)(*&^%$#@!,", b$)
        IF bad > 0 THEN b$ = "0"

        b = VAL(b$)
        LOCATE CSRLIN - 1, 1
        IF b <= 0 OR b >= .187 THEN
            LOCATE CSRLIN, 21: PRINT "*** Incorrect Entry ***"
            FOR repeat = 1 TO 3
                SOUND 1650, .2
                FOR delay = 1 TO 1000: NEXT delay
            NEXT repeat
            SLEEP 2
            LOCATE CSRLIN - 1
            LOCATE CSRLIN, 18: PRINT STRING$(30, 255)
            LOCATE CSRLIN - 1
        END IF
        LOOP UNTIL b > 0 AND b < .187
    PRINT
END SUB
```