MR 277 ✓

AUTHORS: Phillips RD, Hunt EL, King NW:

DATE: 1975

TITLE: Field measurements, absorbed dose, and biologic dosimetry of microwaves.

SOURCE: Annals of the New York Academy of Sciences, Vol 247:499-509

00037009

MAIN SUBJECT HEADING:

[✓ AN]	HU	AT	IH	M
ANALYTICS	HUMAN EFFECTS	ANIMAL TOXICITY	WORKPLACE PRACTICES-ENGINEERING CONTROLS	MISCELLANEOUS

SECONDARY SUBJECT HEADINGS: AN HU AT IH M

Physical/Chemical Properties

Review

Animal Toxicology

Non-occupational Human Exposure

Occupational Exposure

Epidemiology

Standards

Manufacturing

Uses

Reactions

Sampling/Analytical Methods

Reported Ambient Levels

Measured Methods

Work Practices

Engineering Controls

Biological Monitoring

Methods of Analysis

Treatment

Transportation/Handling/Storage/Labelling

3. Crawford, M. L., G. A. Haci & E. L. Komarek. 1971. RF differential power measurement system for the Brooks AFB electromagnetic radiation hazards experiments. NBS Report 9795, Institute of Basic Standards.
4. Johnson, C. C. 1973. Personal communication to J. W. Frazer, USAF School of Aerospace Medicine, Brooks Air Force Base, Texas.

◆

Discussion

Dr. H. S. Ho: In your animal experiments, do you see a change in absorbed power as the animal moves around?

Mr. Allen: You can see some slight alterations in power absorption as the animal moves. The change is less than 5%. We have also performed measurements with the rhesus monkey and have found orientation effects. If the animal is oriented in an upright position, aligned with the *E* field, more power is absorbed than if the animal is turned over with the long axis perpendicular to the *E* field.

Mr. W. W. Mumford (*Morris Plains, N.J.*): Is your instrumentation sensitive enough to measure reflection coefficients if the field strength is as low as 192 V/m?

Mr. Allen: With a 50-W input, in our cage, we are describing a field of 1.3 mW/cm^2. We did not see any statistic difference between the fields. The measurement is extremely sensitive. The differential power measurement system and its couplings were built and calibrated by the National Bureau of Standards. With the 50-W input, for instance, we can measure values of absorbed power as low as 0.01W.

MR 277

FIELD MEASUREMENTS, ABSORBED DOSE, AND BIOLOGIC DOSIMETRY OF MICROWAVES*

Richard D. Phillips, Edward L. Hunt,† and Nancy W. King

Biology Department
Battelle, Pacific Northwest Laboratories
Richland, Washington 99352

Introduction

A variety of exposure arrangements have been used for irradiating experimental animals with microwaves to study the biologic effects. Methods of dosimetry and ways of expressing radiation dose have been equally diverse. Without a common dose unit, it has been very difficult, if not impossible in many cases, to compare the biologic effects produced with different exposure arrangements. There is an obvious need to establish a uniform method of expressing radiation dose if we are to be able to compare results between studies.

Various solutions to the dosimetry problem have been proposed and investigated,[1–6] but the problem of measuring the amount of energy absorbed by biologic materials continues to plague investigators. Several years ago, we developed a technique for measuring the amount of energy an animal absorbs when exposed to microwaves in a cavity arrangement.[7–11] Recently, we have applied this technique to determine absorbed doses with far-field exposures of rats in an anechoic chamber and with exposures in the multimodel resonating cavity. We compared the biologic effects produced by these two treatment arrangements at equivalent radiation doses. In addition, we determined the accuracy with which physical models of rats could be used for estimating energy absorption by the whole animal in both irradiation arrangements.

Microwave Exposure Systems

Two microwave exposure arrangements were used: a multimodal resonating cavity system, in which the animal serves as the load and is exposed multilaterally; and a far-field exposure system in an anechoic chamber, in which the animal is exposed unilaterally to a well-defined incident field.

Multimodal Resonating Cavity Exposure System

A block diagram of the system used for exposing animals to microwaves in the cavity is shown in Figure 1. The cavity is powered by a magnetron source operated at 2450 MHz with a pulse repetition rate of 120 Hz. In this study, the output power of the source was adjusted to 175 W, which produced pulses of 2.5 msec duration. A three-port circulator is located in the wave guide to protect the magnetron from

---

*Supported by Office of Naval Research Contracts N00014-70-C-0197 and N00014-70-C-0332 with funds provided by the Bureau of Medicine and Surgery, Department of the Navy.

†Present address: Department of Microwave Research, Walter Reed Army Institute of Research, Washington, D.C. 20012.

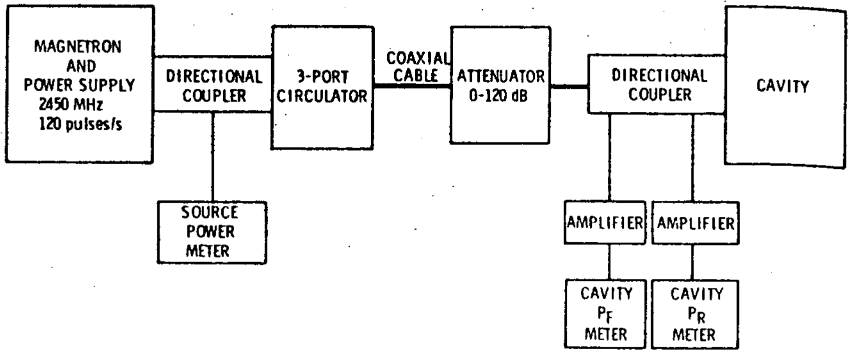

FIGURE 1. Block diagram of multimodal resonating cavity exposure system.

reflected power and reduce moding of the magatron. Power delivered to the cavity is adjusted with the variable attenuator. Crystal detectors in the bidirectional coupler and calibrated power meters were used to measure forward and reflected powers at the cavity input. Temperature and relative humidity within the cavity were maintained at approximately 24°C and 20–40%, respectively, by a forced-air ventilation system. In this exposure system, the animal serves as the working load in the cavity, and when the animal is positioned in a standard location, it absorbs energy in proportion to net power delivered to the cavity.[7,11]

Far-Field Exposure System

The arrangement employed for exposing animals in the far field of a transmitting antenna in an anechoic chamber is shown in FIGURE 2. The source is an APS-20E radar transmitter with a coaxial magnetron. It generates 2880 MHz microwaves at 925 or 308 pulses/sec, with pulse widths of approximately 0.8 and 2.4 μsec, respectively. A circulator has been added to the system to protect the magnetron from reflected power; a variable attenuator is used for adjusting the power level to the transmitting antenna; and calibrated power meters connected to directional couplers are utilized to measure forward and reflected powers in the wave guide. The transmitting antenna, located in the anechoic chamber, is a horn with a 16.1-dB gain. The transmission system is pressurized with nitrogen gas at 10 psig to reduce the possibility of arcing within the system.

The anechoic chamber consists of a radio-frequency-shielded room lined with microwave-absorbent material. The anechoic, or specimen exposure, space is located in the far field of the antenna and extends from 4 to 10 ft from the aperture of the horn antenna. The anechoic space is 2 ft wide by 1 ft high, with its geometric center located on the beam axis. Reflectivity measurements were achieved with the free-space voltage standing wave ratio technique. It was found that the reflected power into this space from the ceiling, floor, side walls, and back wall is decreased at least 45 dB from the main beam power. The cross polarization of the chamber is −38.5 dB, which shows that the room does not appreciably alter the plane of polarization of the beam from the transmitter antenna. Temperature within the chamber was maintained at about 24°C by a ventilation system that exchanges the room air approximately 60 times per minute. The relative humidity during these experiments ranged from 20 to 40%.

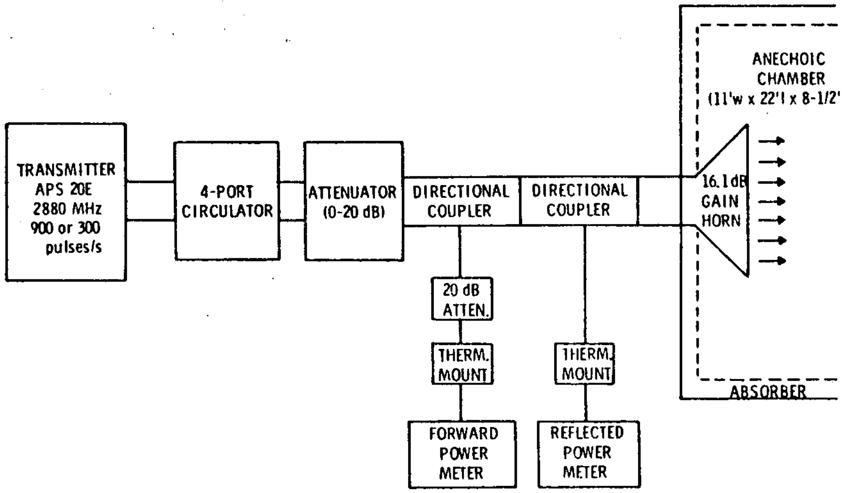

FIGURE 2. Block diagram of far-field exposure system.

Power densities were measured in the far field by a standard procedure.[8] A 16.1-dB receiving antenna, identical to the transmitting antenna, was placed in the far field at the location of interest. Both antennas were oriented with their electric fields horizontal. A given power level, measured in the wave guide at the directional coupler, was delivered to the transmitting antenna. The power absorbed by the receiving antenna was conducted through wave guide and coaxial cable of known characteristics to a thermistor power bridge. The power density was calculated from the following equation:[8]

$$P_d = \left(\frac{4\pi}{9 \times 10^8}\right) f^2 \left(\frac{A}{G}\right) P_t,$$

where P_d represents the power density (mW/cm^2), f equals the frequency of radiation (MHz), A is the attenuation of the coupling circuit, G denotes gain of receiver antenna, and P_t represents the power registered on the thermistor power bridge (mW). For the arrangement employed, the attenuation of the coupling circuit was 24.85 dB, the gain of the receiver antenna was 16.1 dB, and the frequency of the source was 2880 MHz. Insertion of these values in the equation gives the result, $P_d = 0.88\, P_t$.

We made a mathematic analysis of the conjugate mismatch uncertainties of the coupling circuit used for the power density measurements.[9,10] The lower and upper conjugate mismatch loss limits were −0.2 and 0.8 dB, respectively, which yields an uncertainty range of 1 dB. With this potential error source in the power density determinations, and all other potential instrument errors included, the total uncertainty of the absolute accuracy of the power density measurement was −11 to 32% of the stated values.

Power density measurements were performed 7 ft from the transmitting antenna with different forward powers in the wave guide (FIGURE 3). A linear relationship exists between the power density measurements and the forward power measured in

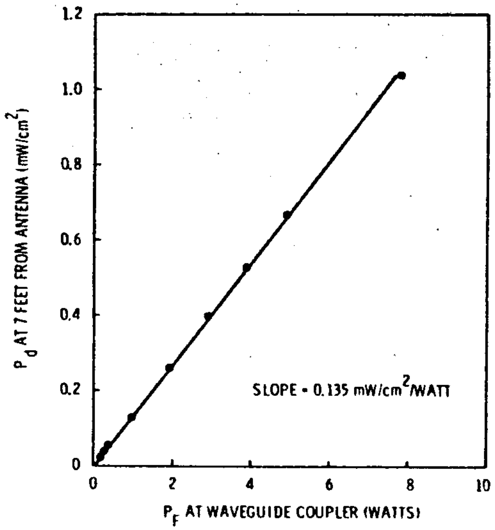

FIGURE 3. Power density at 7 ft from the transmitting horn antenna in the anechoic chamber with different forward powers in the wave guide.

the wave guide at the directional coupler. Reflected power is minimal in this system, less than 0.2% of the forward power, and can be ignored (FIGURE 4).

Power densities were also determined in the far field at different distances from the transmitting antenna. FIGURE 5 depicts the power densities in the far field as a function of distance from the receiving antenna, with the transmitting antenna operated at a forward power of 352 W. The data fit the inverse square law, with the isotropic reference point located 18 in. behind the horn antenna aperture.

ABSORBED DOSE MEASUREMENTS

We have previously described the technique utilized for determining the absolute amount of energy absorbed by animals exposed to microwaves in a cavity arrangement.[7,11] The same technique is used for determining the amount of energy absorbed with far-field exposures. Briefly, this value is determined by measuring the amount of heat generated in a fresh rat carcass irradiated with microwaves by use of a differential, or twin-well, calorimeter. The general procedure consists of placing a pair of freshly killed rats of equivalent body weight into a twin-well calorimeter and calculating the differential body heat content of the pair. Both carcasses are then removed from the calorimeter and placed in insulated containers constructed of expanded bead polystyrene. One animal is then exposed briefly to microwaves in either the cavity or in the far field in the anechoic chamber. The other animal serves as a sham-exposed control and reference heat source. Immediately after treatment, both animals are put back into the calorimeter, and the heat added to one animal's body heat by irradiation is measured. Use of dead animals eliminates the problems of physiologic heat production and loss and requires only the assumption that death does not alter the lossiness of animal tissues for absorption of microwave energy. The accuracy of this technique for determining the absolute amount of energy absorbed by rats has been calculated to be 0.8%.[12]

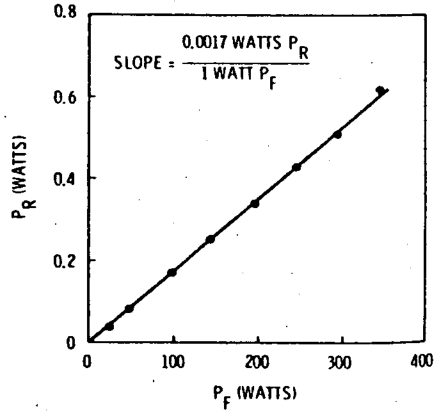

FIGURE 4. Relationship between forward and reflected powers in the wave guide.

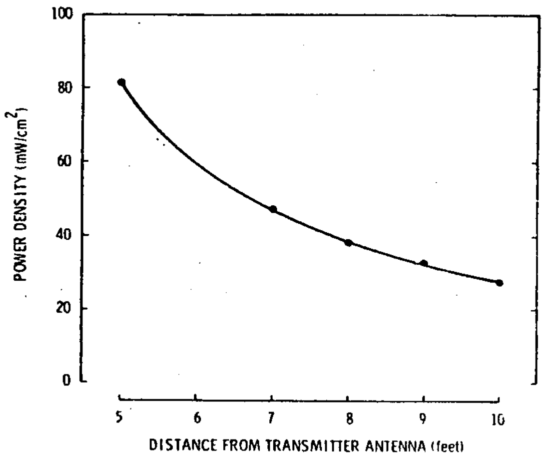

FIGURE 5. Power densities in the far field at different distances from the transmitting antenna operated at a forward power of 352 W.

Absorbed Doses with Cavity and Far-Field Exposures

By means of the calorimetric technique, we measured the absorbed dose in rats exposed to microwaves in the cavity and in the far field of a transmitting antenna in the anechoic chamber. Determinations were made for three different sizes of animals in each treatment arrangement.

The amounts of energy absorbed by rats irradiated in the cavity are listed in TABLE 1. The mean and standard error values given in the Table are based on determinations from five animals in each weight group. The total amount of energy absorbed in a 1-min exposure for each watt of net cavity power increased with body mass. The absorption efficiencies can be calculated by comparing the total amount of energy absorbed to that which is available. The absorption efficiencies of 190-, 289-, and 375-g rats were 43.3, 48.2, and 51.6%, respectively. When the absorbed

TABLE 1

ENERGY ABSORBED (MEAN ± SE) BY RATS EXPOSED IN A CAVITY TO 2450 MHz MICROWAVES FOR 1 MIN FOR EACH WATT OF NET POWER AT CAVITY

Body Mass (g)	N	Total Surface Area* (cm²)	Total Energy Absorbed (J)	Mass Absorption Density (mJ/g)	Total Area Absorption Density (mJ/cm²)
189.6 ± 1.1	5	357	26.0 ± 0.5	137.2 ± 2.8	78.2 ± 1.5
288.6 ± 3.0	5	437	28.9 ± 0.5	100.1 ± 1.7	66.1 ± 1.1
374.5 ± 2.8	5	565	31.1 ± 0.5	82.9 ± 1.3	55.0 ± 0.8

*Altman and Dittmer.[13]

energies are expressed per unit of body mass, or as mass absorption densities, the average energy absorbed per gram decreased with an increase in body mass. The area absorption densities, which reflect average energy absorption per unit total surface area of the animals,[13] also declined with an increase in body mass.

TABLE 2 gives the absorbed dose values for rats exposed in the far field of the transmitting antenna in the anechoic chamber. The values shown are means and standard errors and are based on measurements from six animals in each weight group. The absorbed energies are normalized for a 1-min exposure for each mW/cm² of field power density. As with cavity irradiation, the total energy absorbed increased with body mass. The mass absorption densities were the same for the two heaviest weight groups and slightly higher for the lightest weight group. The silhouette area absorption densities, which reflect the average absorption per unit of shadow cross-sectional area of the animals,[3] did not change with animal size. If the total energy absorbed is compared to the amount of energy available for absorption on the basis of the silhouette surface area, it is found that the animals absorb about 67% of the available incident energy.

Comparison of Energy Absorbed by Models and Rats

Many investigators use biophysical models for estimating absorbed doses in cavity irradiations and far-field exposures.[3–6,14–18] Such models usually simulate the weight and volume of the animal and are shaped like spheres or cylinders. They are composed of water or a homogeneous mixture of materials that simulate the average dielectric properties of the whole animal or particular tissues. Because animals are heterogeneously structured of differently shaped tissues that vary in their composition and dielectric properties, it is not known how accurately simplified models estimate energy absorption by the whole animal.

TABLE 2

ENERGY ABSORBED (MEAN ± SE) BY RATS EXPOSED UNILATERALLY IN THE FAR FIELD TO 2880 MHz MICROWAVES PER MINUTE PER mW/cm² FIELD POWER DENSITY

Body Mass (g)	N	Silhouette Area* (cm²)	Total Energy Absorbed (J)	Mass Absorption Density (mJ/g)	Silhouette Area Absorption Density (mJ/cm²)
196.6 ± 3.6	6	85	3.43 ± 0.15	17.5 ± 0.8	40.4 ± 1.8
296.7 ± 2.8	6	105	4.13 ± 0.08	13.9 ± 0.3	39.5 ± 0.9
378.0 ± 4.4	6	125	5.17 ± 0.08	13.7 ± 0.2	41.5 ± 0.6

*Justesen and King.[3]

TABLE 3

COMPARISON OF ENERGY ABSORBED (MEAN ± SE) BY RATS AND WATER MODELS EXPOSED IN A CAVITY TO 2450 MHz MICROWAVES FOR 1 MIN PER WATT NET POWER AT CAVITY

Mass (g)	Rats	Models	Difference (%) (Models − Rats)
	Mass Absorption Density (mJ/g)		
190	137.2 ± 2.8	145.8 ± 1.8	+6.2†
290	100.1 ± 1.7	104.4 ± 1.2	+4.4†
	Area Absorption Density (mJ/cm²)		
190	78.2 ± 1.1*	212.1 ± 2.6‡	+170†
290	66.1 ± 1.1*	178.9 ± 2.1‡	+170†

*Total surface areas of 190- and 290-g rats were 357 and 437 cm², respectively.[13]
†$p < 0.05$.
‡Total surface areas of 190- and 290-g models were 129 and 166 cm², respectively.

We tested the accuracy of one type of model for estimating absorbed energy by the whole animal. The model is a cylindrical vessel composed of expanded bead polystyrene lined with a thin layer of Silastic® and filled with water.[7] The amounts of energy absorbed by two sizes of models, 190 g (17 cm long by 3.8 cm diameter) and 290 g (19.6 cm long by 4.5 cm diameter), were compared to those of rats of the same weights. The procedures used for irradiation and calorimetry were the same for the rats and models. Absorbed dose measurements were conducted on five water models and five rats, for each of two sizes, in each treatment arrangement.

TABLE 3 summarizes the results for rats and models exposed to microwaves in the cavity. The models only slightly overestimated the mass absorption densities of rats of comparable weight. In terms of the total area absorption densities, there were marked differences between models and rats. The values obtained with water models were 170% higher than those obtained with rats of the same weight.

A comparison of energy absorbed by rats and models exposed unilaterally to microwaves in the far field is illustrated in TABLE 4. In terms of the mass absorption densities, the water models underestimated the energy absorbed by rats by about 13%. This finding contrasts with the results obtained with cavity irradiations, where values based on models overestimated energy absorption of rats by about 5%. In terms of the silhouette area absorption densities, the values obtained with water models did not differ reliably from those of rats.

It is evident that extreme care must be used when energy absorption for the whole animal is estimated from models. With cavity irradiations, the mass absorption density appears to be the appropriate unit for estimating absorbed doses with models. With unilateral far-field exposures, the silhouette area absorption density appears to be useful for estimating absorbed doses with models. It is important to note that the results of these comparisons between models and rats only provide information as to the relative importance of mass and area for determining absorbed doses with cavity and far-field exposures and indicate nothing about the biologic relevance of either the mass absorption density or the area absorption density.

TABLE 4

COMPARISON OF ENERGY ABSORBED (MEAN ± SE) BY RATS AND WATER MODELS EXPOSED UNILATERALLY IN THE FAR FIELD TO 2880 MHz MICROWAVES PER MINUTE PER mW/cm^2 FIELD POWER DENSITY

Mass (g)	Rats	Models	Difference (%) (Models − Rats)
	Mass Absorption Density (mJ/g)		
190	17.5 ± 0.8	15.2 ± 0.7	−13.1*
290	13.9 ± 0.3	12.0 ± 0.3	−13.7*
	Silhouette Area Absorption Density (mJ/cm^2)		
190	40.4 ± 1.8†	44.3 ± 3.0‡	ns§
290	39.5 ± 0.9†	40.5 ± 0.3‡	ns

*$p < 0.05$.
†The silhouette areas of 190- and 290-g rats were 85 and 105 cm^2, respectively.[3]
‡The silhouette areas of 190- and 290-g models were 66 and 85 cm^2, respectively.
§ns, not significant.

BIOLOGIC EFFECTS OF CAVITY AND FAR-FIELD EXPOSURES

We have obtained some biologic data that indicate that the average absorption of energy per unit mass is a useful parameter for expressing dose with cavity irradiations. In one experiment, we measured the latency for inducing convulsive seizures in rats during cavity exposures. With four different sizes of male rats of the Wistar strain, which ranged in weight from 190 to 562 g, a family of dose-response curves was obtained when latency to convulsions was plotted in terms of net power delivered to the cavity (FIGURE 6). As the weight of the animal increased, so did the latency at a given power level, even though the heavier animal absorbed more total energy. When the same data are replotted according to the rate at which energy is absorbed per gram of tissue, based on the calorimetric measurements, the curves are no longer separated (FIGURE 7), and the data will fit a single curve. A similar study has been conducted in C57BL/6J mice (cf. FIGURE 7), and their responses fit the dose-response curve of rats. For this one biologic endpoint, latency to thermally induced convulsions, the average energy absorbed per unit mass appears to be a meaningful and useful parameter.

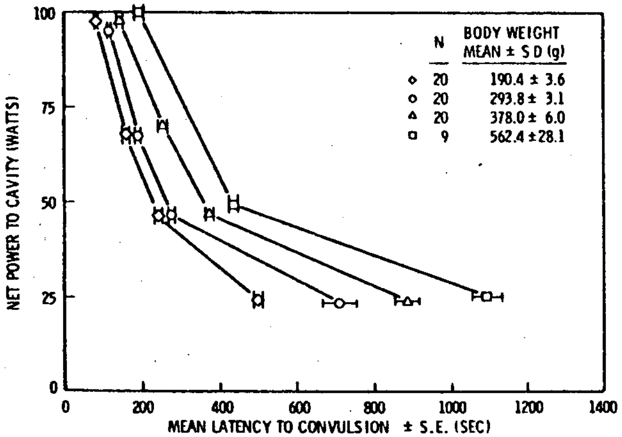

FIGURE 6. Latency to convulsions in rats during microwave irradiation with different net powers delivered to the cavity.

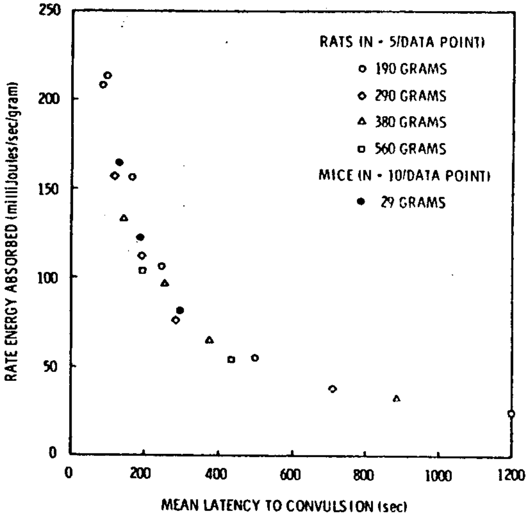

FIGURE 7. Latency to convulsions in rats and mice during microwave irradiation as a function of the rate at which energy is absorbed per gram of tissue.

We do not know if the same relationship between absorbed dose rate and latency to convulsions would be obtained in rats and mice exposed unilaterally in the far field in the anechoic chamber. Power of sufficient magnitude to induce convulsions in rats cannot be generated in most far-field exposure systems, including the one used in this study. It may be possible to investigate this problem with mice as the test subjects. Because mice have a mass absorption density approximately 10 times that of rats, it should be possible to produce convulsions at much lower power densities in the far field.

We have initiated a series of experiments to compare the biologic responses of rats exposed in the cavity to those of rats irradiated in the far field in the anechoic chamber. Although we have obtained only preliminary data at this time, it is apparent that the biologic responses are different under these two treatment arrangements. Both qaauntitative and qualitative differences in responses have been observed over an equivalent range of absorbed doses.

Rats exposed to microwaves in the cavity for 30 min at an absorbed dose rate of 11.5 mW/g die within 24 hr after irradiation. A similar response is observed in rats irradiated unilaterally in the far field at an absorbed dose rate of only 8.3 mW/g for 30 min. Marked differences also occur in physiologic responses between animals irradiated in both exposure arrangements. With cavity irradiation, an array of functional changes occurs within 1-3 hr after a 30-min exposure at a dose rate of 6.5 to 11.0 mW/g.[19] Typically, the irradiated animal will exhibit thermoregulatory overcompensation, a lowered metabolic rate, bradycardia, irregular heart rate, and incomplete heart blockage. None of these functional alterations have been observed in rats exposed to microwaves in the far field for 30 min at comparable dose rates.

There are several possible explanations for these differences in biologic responses to irradiation under these two exposure arrangements. With a cavity exposure the animal is irradiated multilaterally, while with far field exposures the animal is irradiated unilaterally. This would be expected to result in marked differences in distribution of absorbed energy that could lead to different biologic responses. Also, the frequency and pulsing characteristics of the microwave sources for the cavity and far-field exposure systems were different. The appropriate experiments need to be made to eliminate these differences. We have recently modified our exposure systems, so that the same source can be used for either the cavity or the anechoic chamber.

CONCLUSIONS

Four major implications of this study are:

The mass absorption density appears to be a useful dose unit for comparing biologic effects produced with different exposure arrangements. Other measures, such as silhouette area absorption density, may be useful for a particular geometry but not for others.

The use of models for estimating energy absorption by animals must take into consideration the geometry of the exposure arrangement. With cavity irradiation, the mass of the load appears to be the important factor. In unilateral far-field irradiations, the silhouette surface area of the object is the important factor.

It may not be possible to generalize information derived from cavity irradiations to far-field exposure conditions.

A safety standard based on incident field densities and based on data from experiments with far-field exposures may not be applicable under conditions where multilateral irradiations occur.

REFERENCES

1. Anne, A., M. Saito, O. M. Salati & H. P. Schwan. 1961. Relative microwave absorption cross sections of biological significance. *In* Biological Effects of Microwave Radiation. M. F. Peyton, Ed. Vol. 1: 153–176. Plenum Publishing Corporation. New York, N.Y.
2. Vogelman, J. H. 1961. Microwave instrumentation for the measurement of biological effects. *In* Biological Effects of Microwave Radiation. M. F. Peyton, Ed. Vol. 1: 23–31. Plenum Publishing Corporation. New York, N.Y.
3. Justesen, D. R. & N. W. King. 1969. Behavioral effects of low level microwave irradiation in the closed space situation. *In* Biological Effects and Health Implications of Microwaves. S. F. Cleary, Ed. Report BRH/DBE 70-2: 154–184. Department of Health, Education and Welfare, Bureau of Radiological Health. Washington, D.C.
4. Justesen, D. R., D. M. Levinson, R. L. Clarke & N. W. King. 1971. A microwave oven for behavioral and biological research: electrical and structural modifications, calorimetry, dosimetry, and functional evaluation. J. Microwave Power 6: 237–258.
5. Guy, A. W. & S. F. Korbel. 1972. Dosimetry studies of a uhf cavity exposure chamber for rodents. *In* Microwave Power Symposium, Summaries of Presented Papers.: 180–193. International Microwave Power Institute. Edmonton, Alberta, Canada.
6. Lin, J. C., A. W. Guy & G. H. Kraft. 1974. Microwave selective brain heating. J. Microwave Power 8: 275–286.
7. Hunt, E. L. & R. D. Phillips. 1972. Absolute dosimetry for whole animal experiments. *In* Joint Army/Georgia Institute of Technology Microwave Dosimetry Workshop.: 74–77. Walter Reed Army Institute of Research. Washington, D.C.
8. Grissom, J. L. 1970. Determination of radiated rf power density. Electr. Instr. Dig. 6: 61–63.
9. Beatty, R. W. 1963. Intrinsic attenuation. IEEE Trans. Microwave Theory Tech. MTT-11(3): 179–182.
10. Beatty, R. W. 1964. Insertion loss concepts. Proc. IEEE 52(6): 663–671.
11. Phillips, R. D. & E. L. Hunt. 1971. Problems of physical and biological dosimetry of microwave irradiation. J. Microwave Power 6:90 (abs.).
12. Hunt, E. L., R. D. Phillips, D. M. Fleming & R. D. Castro. Dosimetry for whole-animal microwave irradiation. Health Phys. Submitted for publication.
13. Altman, P. L. & D. S. Dittmer. (Eds.) 1962. *In* Growth.: 538. Federation of American Societies for Experimental Biology and Medicine. Washington, D.C.
14. Mermagen, H. 1961. Phantom experiments with microwaves at the University of Rochester. *In* Biological Effects of Microwave Radiation. M. F. Peyton, Ed. Vol. 1: 143–152. Plenum Publishing Corporation. New York, N.Y.
15. Johnson, C. C. & A. W. Guy. 1972. Nonionizing electromagnetic wave effects in biological materials and systems. Proc. IEEE 60: 692–718.
16. Ho, H. S., A. W. Guy, R. S. Sigelmann & J. F. Lehmann. 1971. Microwave heating of simulated human limbs by aperture sources. IEEE Trans. Microwave Theory Tech. MTT-19(2): 224–231.
17. Guy, A. W. 1971. Analyses of electromagnetic fields induced in biological tissues by thermographic studies on equivalent phantom models. IEEE Trans. Microwave Theory Tech. MTT-19(2): 205–214.
18. Schwan, H. P. 1971. Interaction of microwave and radiofrequency radiation with biological systems. IEEE Trans. Microwave Theory Tech. MTT-19(2): 146–152.
19. Phillips, R. D., E. L. Hunt & N. W. King. 1973. Physiologic response of rats to hyperthermia induced by exposure to 2450 MHz microwave radiation. Physiologist 16(3): 423 (abs.).

DISCUSSION

DR. C. WILEY (*Environmental Protection Agency, Research Triangle Park, N.C.*): What was the shape of the model that you used?

DR. PHILLIPS: The model was a cylinder-shaped vessel.

DR. WILEY: Did you use any form of cooling in the cavity?

DR. PHILLIPS: The cavity has a forced-air ventilation system. We monitored but did not control the temperature. Typically, the temperature after the equipment had been running for awhile would be about 73° F. The temperature would increase by about 0.5° F during a 30-min exposure because of the heat generated by the equipment.

DR. A. W. GUY: We have verified that you do obtain hot spots in the rat with average absorbed power densities as you are measuring. The spherical model theory seems to also confirm this finding. You can obtain peak absorbed power densities up to approximately five times the average. The value is in the range of typical localized diathermy treatments, between 50 and 100 mW/g.