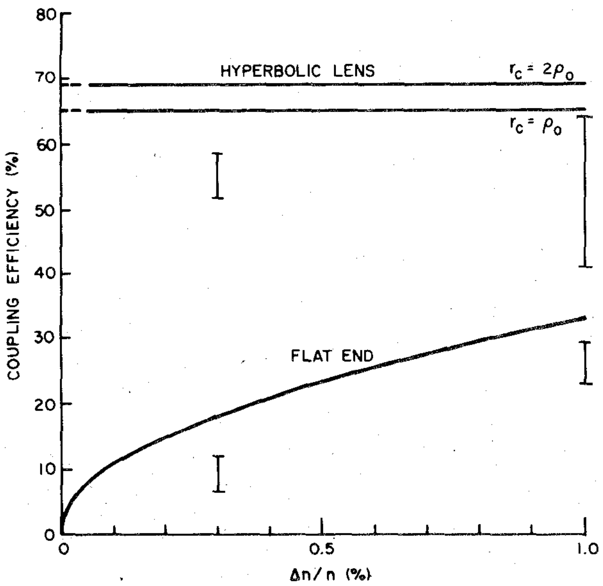

Fig. 4. Theoretical coupling efficiencies as functions of $\Delta n/n$ for hyperbolic lens and flat-end coupling. A typical radiation pattern of GaAs injection laser is assumed.

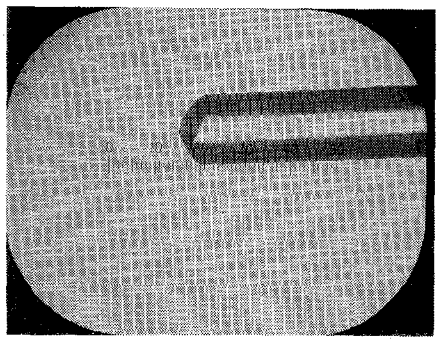

Fig. 5. A mechanically polished sample (soda-lime-silicate).

and one end is ground into a wedge form using a Norton abrasive wheel mounted on a Buehler metallurgical lapping machine. The final lapping and polishing are done on a politex lapping disk using 3-μ aluminum oxide abrasive. Fig. 5 shows a mechanically polished sample. For flame-polished samples, the fiber is first ground into a wedge shape as before and then melted (flame-polished) to form a cylindrical lens.

Coupling measurements are made using a GaAs injection laser operating on a pulse basis. A 20 $\sim$ 25-cm piece of the fiber under test is coated over its entire length with black India ink to act as a stripping agent. Its effectiveness was carefully checked using both near-field and far-field measurements and the contribution of the cladding modes was found to be negligible (less than 3 percent). The end with the lens is placed in an x,y,z positioner with the wide plane of the lens parallel to the laser face and the other end against a power meter. The fiber lens position and angle are optimized for a maximum power meter reading. The ratio of this meter reading to the output power of the laser gives the coupling efficiency. The error due to the reflection from the power meter end of the glass fiber is neglected.

Using soda-lime-silicate glass fiber with core diameter 80 μ and $\Delta n/n = 0.3$ percent and quartz glass fiber with core diameter 39 μ and $\Delta n/n = 1$ percent, several lens and flat-end coupling experiments have been made. The range of coupling efficiency obtained with these samples is indicated in Fig. 4 in addition to the theoretical results. From this, it is seen that the coupling efficiency is improved by a factor of 5 for $\Delta n/n = 0.3$ percent and by a factor of 2 for $\Delta n/n = 1$ percent over the flat-end coupling. In comparison, spherical lenses fabricated on the soda-lime-silicate glass fiber ($\Delta n/n = 0.3$ percent) improved the coupling efficiency by a factor of 4 over the flat-end coupling when tested with a different GaAs injection laser having slightly narrower beamwidth than the present experiment [4].

V. CONCLUSION

A hyperbolic lens is proposed for improving the coupling efficiency between GaAs injection lasers and glass fibers. Several samples fabricated indicate that the proposed lens is practical for improving the coupling efficiency. No attempt has been made to fabricate a large number of lenses in one operation, but this does not seem difficult. Also no attempt has been made to make lenses on single-mode fibers, but our fabrication method indicates that very sharp wedges can be made on quartz fibers and hence the method can be readily extended to single-mode fibers.

ACKNOWLEDGMENT

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REFERENCES

[1] L. G. Cohen, "Power coupling from GaAs injection lasers into optical fibers," *Bell. Syst. Tech. J.*, vol. 51, pp. 573–594, 1972.
[2] L. G. Cohen and M. V. Schneider, "Microlenses for coupling junction lasers to optical fibers," *Appl. Opt.*, vol. 13, pp. 89–94, Jan. 1974.
[3] D. Kato, "Light coupling from a stripe-geometry GaAs diode laser into an optical fiber with spherical end," *J. Appl. Phys.*, vol. 44, pp. 2756–2758, June 1973.
[4] C. A. Brackett, "On the efficiency of coupling light from stripe geometry GaAs lasers into multimode optical fibers," *J. Appl. Phys.*, vol. 45, pp. 2636–2637, June 1974.
[5] H. C. Casey, Jr., M. B. Panish, and J. L. Merz, "Beam divergence of the emission from double heterostructure injection lasers," *J. Appl. Phys.*, vol. 44, pp. 5470–5475, Dec. 1973.

RF Cavity Irradiation Dosimetry

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***Abstract*—A right circular cylindrical cavity designed to resonate at 380 MHz was developed to irradiate a monkey head with little or no radio frequency exposure to other tissues. The system is used in studies of the behavioral effects of the absorption of radiant power. Dose-rate measurements were made with an electrically equivalent calorimetric load, consisting of a saline-filled plastic cylinder whose geometry and position in the cavity reproduced cavity and transmission line parameters measured with a test animal. Since integral dose rate P_m (total power absorbed) is proportional to the net power transmitted to the cavity P_t, the constant of proportionality $K_m = P_m/P_t$ must account for the absorption of field energy by the tissue. K_m was determined by comparing the temperature rise produced in a fixed time period by the dissipation of dc power to the temperature rise produced by RF radiation in the same time period. It was found that, at an ambient temperature of 25±2°C and a relative humidity of 55±5 percent, K_m was 0.62.**

INTRODUCTION

Microwave heating may insult a variety of organ systems [1]. In addition, the existence of nonthermal bioeffects has also been sug-

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gested [2]. Such reports have given rise to a controversy [3] over safe levels of exposure to microwave radiation. Since energy must be deposited in tissue in order to produce a biological effect, it is probable that much of the confusion over the biological effects of such radiation is due to the lack of quantification of the amount of energy absorbed during irradiation.

In experiments reporting microwave bioeffects, the radiation is typically quantified in terms of incident power density (exposure rate, mW/cm^2). However, it has been shown [3], [4] that the amount of microwave energy absorbed by a biological body is dependent on the frequency and geometry of the radiation field, and on the geometry, size, orientation, and complex dielectric constant of the specimen. Since dose rate (time rate of energy absorbed per unit mass at a location) is more directly related to biological effects than is exposure rate (power density), we have developed an irradiation facility and a calorimetric technique for the determination of integral dose rate (time rate of total energy absorbed) in a monkey's head irradiated in a 383-MHz resonant cavity. The facility is used for studying the effects of radio frequency (RF) radiation on the central nervous systems of unanesthetized rhesus monkeys.

RESONANT CAVITY

A block diagram of the cavity irradiation system is shown in Fig. 1. The cavity is a right circular cylinder of radius 47.9 cm and a height of 45.2 cm (Fig. 2). The wall is constructed of aluminum screen (16 mesh per inch). The top and bottom plates are $\frac{1}{8}$- and $\frac{1}{4}$-in-thick aluminum sheets, respectively. The cavity is supported by three, 1-in-diameter aluminum rods extending from the bottom plate to the floor. A monkey restraining chair is attached to the three rods. The bottom plate has a 9-cm-diameter hole in the center through which the monkey's head protrudes. The cavity is sealed by four clear acrylic plastic sheets and the internal atmosphere is circulated and conditioned. The air is held at a temperature of $24 \pm 0.5C°$ and a relative humidity of 55 ± 5 percent.

The cavity is excited by a loop-type probe (see Fig. 3). The loop lies in the plane of the cavity diameter and enters into the cavity 6 cm above the bottom plate in a direction facing the test animal. One end of the loop is soldered to the center conductor of a UG-560/u amphenol chassis mount connector (fixed). The other end of the loop passes through the cavity side wall (finger stock is used to provide grounding) and extends 8 cm outside the cavity. The loop is not one continuous piece, but is made to periscope as the outside extended part is pulled out or pushed in. The loop has a radius of 3.75 cm, and thicknesses of 3 mm and 5 mm for the smaller and larger sections, respectively.

The cavity is designed to resonate in the TE_{111} mode at 380 MHz when empty, and was found to resonate at 383 MHz for the monkey head- or phantom-loaded condition. However, the TM_{110} mode can also be excited by a 3.5-MHz increase in the excitation frequency. The TM_{110} mode was also observed at the lower frequency when the large surface current which flows on the bottom plate was allowed to flow on the neck and head of the test animal. Suppression of this mode was accomplished by providing an air gap between the neck of the animal and the metallic ground plane of the cavity. The gap breaks the path of the current which supports this interfering mode.

The operating mode of the cavity was determined using a perturbation technique [5] in which a 6-cm length of #12 AWG copper wire was suspended and rotated in different positions within the cavity. The orientation of the wire which causes the greatest deviation in voltage, as seen by the sampling probe, indicates the direction of the electric field. The magnetic-field line direction was determined by placing a loop probe through side ports located every 45° around the cavity and through the hole provided for the animal head. The electric-field configuration observed is shown in Fig. 4. The circle denotes the approximate space occupied by the head. This technique was used to map the field in each of three states of interest, namely, empty cavity, monkey head-loaded, and phantom-loaded. The field configuration (cavity mode) was determined to be TE_{111} and is well defined and stable for both the loaded and unloaded cavity.

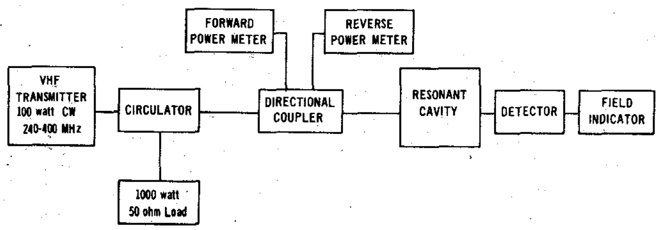

Fig. 1. A block diagram of the 383-MHz resonant cavity irradiation apparatus.

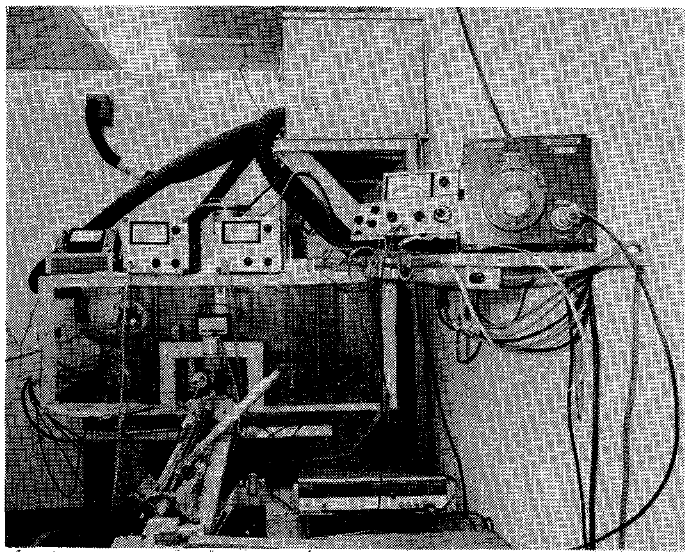

Fig. 2. The irradiation facility.

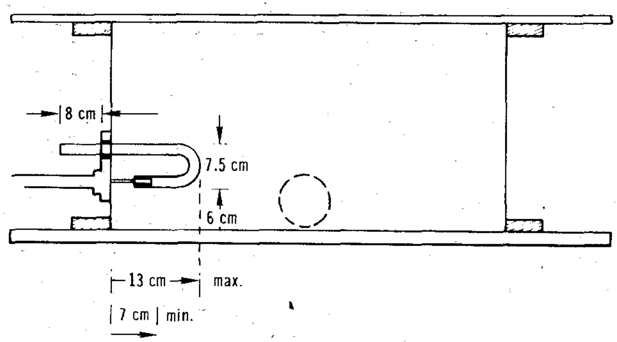

Fig. 3. The cavity excitation probe.

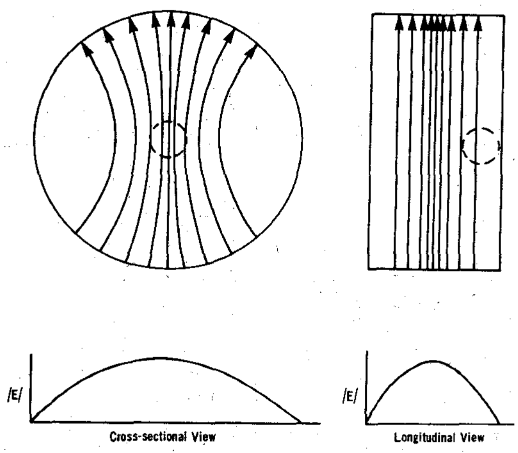

Fig. 4. Electric-field configuration for the TE_{111} mode of resonance. Dotted circle denotes position of the monkey head.

INTEGRAL DOSE-RATE DETERMINATION

An electrical resistance calorimeter was developed which, when placed in the cavity, produces the same mode, cavity, and transmission line parameters as the head of an experimental subject. To develop this load, a monkey was placed in a restraining chair with his head protruding into the cavity, which was tuned to resonate at 383 MHz. The operating frequency and mode were determined and the coupling between the cavity and the transmission line was adjusted to yield a VSWR of 1.08. The monkey was then removed and acrylic cylinders in a variety of sizes, each containing a coil of nichrome heater wire, were filled with normal saline and placed one at a time in the cavity until one was found which produced the same mode and electrical measurements as those obtained with the monkey head as the load. This equivalent load is shown in Fig. 5. A motor driven stirrer was used to prevent temperature gradients during heating.

In order to determine the amount of RF power absorbed by the monkey's head, the equivalent-load calorimeter was heated by a known net RF power P_t (or forward power minus reflected power) for 3 min and the rise in temperature observed. Next the saline-filled cylinder was heated by applying dc voltage across the nichrome wire.

Using (1), the constant of proportionality K_{dc} relating the temperature change ΔT_{dc} to the dc power dissipation P_{dc} and the time interval Δt_{dc} was determined.

$$K_{dc} = P_{dc}\Delta t_{dc}/\Delta T_{dc}. \quad (1)$$

The fraction K_m of the net RF power absorbed by the equivalent load could be determined using (2),

$$K_m = P_m/P_t = K_{dc}\Delta T_m/P_t\Delta t_m \quad (2)$$

where P_t is the net power supplied to the cavity, P_m is the power absorbed by the equivalent load, and ΔT_m and Δt_m are, respectively, the rise in temperature and the duration of RF irradiation of the equivalent load. The integral dose rate ($\dot{\epsilon}$) to the monkey head irradiation in the cavity is then given by

$$\dot{\epsilon} = K_m P_t \quad \text{W}. \quad (3)$$

K_m was determined to be 0.619 ± 0.029 for the load electrically equivalent to a 5-kg monkey. Table I shows typical value recorded during these experiments.

DISCUSSION

This paper has described an irradiation system which permits the determination of the amount of power absorbed by a monkey's head. While the head and neck of the monkey are irradiated in a well-defined field, the rest of the body remains essentially in a zero RF level environment. This allows regular instrumentation to be used in monitoring many biological parameters such as ECG, blood pressure,

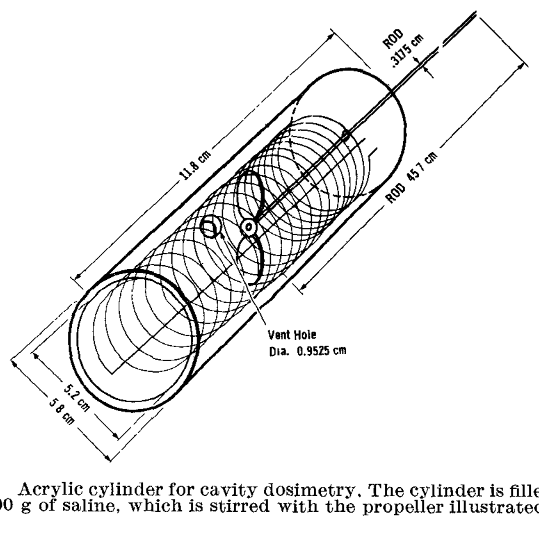

Fig. 5. Acrylic cylinder for cavity dosimetry. The cylinder is filled with 200 g of saline, which is stirred with the propeller illustrated.

TABLE I
CALORIMETRIC RECORDED DATA DURING DC AND RF EXPERIMENTS

No. of D.C. Exper.	T_{dc} C° Start - Finish	ΔT_{dc} C°	Δt_{dc} Sec.	P_{dc} watts	K_{dc}
3	19.4 - 23.3 ± 0.4	3.8 ±0.0	180 ±0.00	7.56 ±0.35	5.94 ±0.39
3	21.6 - 25 ± 0.2	3.4 ±0.1	180 ±1.0	7.79 ±0.01	6.90 ±0.38
3	23.0 - 25.1 ±0.1	2.11 ±0.1	180 ±0.00	3.03 ±0.12	7.15 ±0.22

No. of MW Exper.	T_m C° Start-Finish	ΔT_m C°	Δt_m Sec.	P_t watts	P_m watts (K_{dc} = 7.15)	K_m
6	23.1 - 25.1 ±0.1	2.0 ± 0.0	197.5 ± 10	7.24 ± 0.22	4.49 ± 0.27	0.619 ± 0.029

and body temperature, without mutual interference between the instruments and the radiation field. However, the determination of the distribution of absorbed RF power inside the head is still needed in order to understand microwave-induced effects upon the central nervous system. The equivalent load used in this investigation is insufficient for distributed dose-rate determinations, since the equivalent load represents the monkey head only in terms of the integral dose rate. A preliminary experiment using thermographic techniques and monkey-head models, made of brain equivalent material developed by Guy [6], indicates that the distributed dose-rate pattern produced in this facility is more uniform than reported dose-rate patterns produced in monkey heads by 2450-MHz radiation [7].

REFERENCES

[1] T. S. Ely and D. E. Goldman, "Heating characteristics of laboratory animals exposed to 10 cm microwaves," in *Proc. Tri-Service Conf. Biological Hazards of Microwave Radiation*, 1957.
[2] A. H. Frey, "Biological function as influenced by low-power modulated RF energy," *IEEE Trans. Microwave Theory Tech. (Special Issue on Biological Effects of Microwaves)*, vol. MTT-19, pp. 153–164, Feb. 1971.
[3] C. C. Johnson and A. W. Guy, "Nonionizing electromagnetic wave effects in biological materials and systems," *Proc. IEEE*, vol. 60, pp. 692–718, June 1972.
[4] H. S. Ho, A. W. Guy, R. A. Sigelmann, and J. F. Lehmann, "Microwave heating of simulated human limbs by aperture sources," *IEEE Trans. Microwave Theory Tech. (Special Issue on Biological Effects of Microwaves)*, vol. MTT-19, pp. 224–231, Feb. 1971.
[5] E. L. Ginzton, *Microwave Measurements*. New York: McGraw-Hill, 1957, pp. 300–450.
[6] A. W. Guy, "Analyses of electromagnetic fields induced in biological tissues by thermographic studies on equivalent phantom models," *IEEE Trans Microwave Theory Tech (Special Issue on Biological Effects of Microwaves)*, vol. MTT-19, pp. 205–214, Feb. 1971.
[7] A. R. Shapiro, R. F. Lutomirski, and H. T. Yura, "Induced fields and heating within a cranial structure irradiated by an electromagnetic plane wave," *IEEE Trans. Microwave Theory Tech. (Special Issue on Biological Effects of Microwaves)*, vol. MTT-19, pp. 187–196, Feb. 1971.

Behavioral Suppression by 383-MHz Radiation

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***Abstract*—The heads of two rhesus monkeys were irradiated in a 383-MHz resonant cavity immediately before and during perform-**

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