

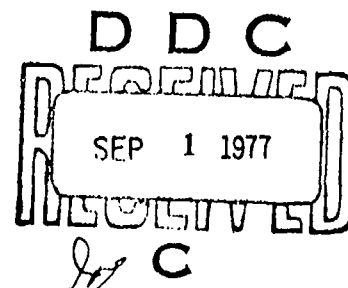
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OPERANT BEHAVIOR AND COLONIC TEMPERATURE OF SQUIRREL
MONKEYS (SAIMIRI SCIUREUS) DURING MICROWAVE IRRADIATION

John de Lorge



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NAVAL AEROSPACE MEDICAL RESEARCH LABORATORY
PENSACOLA, FLORIDA

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OPERANT BEHAVIOR AND COLONIC TEMPERATURE OF SQUIRREL
MONKEYS (SAIMIRI SCIUREUS) DURING MICROWAVE IRRADIATION

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SUMMARY PAGE

THE PROBLEM

Contemporary reports in the scientific and popular press of potentially hazardous effects of exposure to microwaves require substantiation because some Navy personnel contact a variety of microwave devices in communication, warning, and weapons systems. Such putative effects preclude the use of man as a subject; hence, a series of experiments with other primates, monkeys, has been initiated. Research in our laboratory has established that microwave irradiation greater than 62 mW/cm^2 disrupts behavior in rhesus monkeys. In an effort to extend the generality of this finding squirrel monkeys were exposed to microwaves as a second part of the experimental series.

FINDINGS

The behavior of squirrel monkeys on a vigilance task was disrupted by 30- or 60-minute exposures to 50 mW/cm^2 and higher power densities. This disruption increased with the increase in power density. Under both durations of exposure, behavior was not consistently perturbed until colonic temperature changes exceeded 1°C . Colonic temperatures regularly increased, beginning at 10 mW/cm^2 , and were related in a nonlinear fashion to the power density, with a marked acceleration between 40 and 50 mW/cm^2 .

ACKNOWLEDGMENTS

Without the reliable and constant assistance of C.S. Ezell these experiments could not have been successfully completed. In particular, his skills in handling monkeys and constructing various experimental equipment are greatly appreciated. I should also like to thank K. Duncan for her help in data handling and manuscript typing, and T.A. Griner for his help and technical advice.

INTRODUCTION

As part of the Navy's continuing interest in the effects of microwave irradiation a series of studies on the biological effects of microwave exposure was instituted. The primary purpose of these studies is to determine the specific characteristics and power levels of microwaves that are hazardous to man. Because of potential harm to man, other animals must be used and the findings extrapolated to man. A feasible scale for extrapolation could be constructed by using the physical size of biologically similar animals.

Monkeys and man share many similarities. Two important ones are temperature sensitivity (5) and heat exchange between the brain and its blood supply. For these reasons two different sized primates, the rhesus monkey (Macaca mulatta) and the squirrel monkey (Saimiri sciureus), were used in a series of studies. In the initial experiment of the series (2) it was found that rhesus monkeys behaved differentially on an operant task when exposed to 2.45 GHz microwaves at a power density of 72 mW/cm² although body temperature was increased at much lower power densities. The behavioral changes in that study occurred only under conditions where colonic temperature increased more than 1°C.

Surprisingly few microwave studies have even used monkeys as subjects, and to my knowledge no previous investigations regarding microwaves have had squirrel monkeys as subjects. The squirrel monkey is about five times the body mass of the rat (an animal extensively used in microwave bio-effect experiments), one-fifth the body mass of the rhesus, and has the largest brain/body weight ratio (1/17) of all primates (3). The squirrel monkey is also easily trained on tasks that rhesus monkeys can perform, such as the vigilance task used in the previous study (2).

PROCEDURE

SUBJECTS

Four male squirrel monkeys, Saimiri sciureus, weighing between 850 g and 950 g at the beginning of training, were subjected to half-hour exposures to microwaves. Three of these same monkeys were also subjected to one-hour exposures to microwaves. All animals were food deprived and generally worked at weights between 74 and 77 percent of their free-feeding weights. The mean weights of these animals during the half-hour exposure study were: 661 g for monkey 20; 629 g for monkey 26; 684 g for monkey 34; and 672 g for monkey 42. During the one-hour exposure study the mean weights were: 654 g for monkey 26; 718 g for monkey 34; and 719 g for monkey 42.

APPARATUS

A Holaday magnetron unit, Model HI-1200, was the source of the 2450 MHz microwaves which were amplitude modulated at 120 Hz. The radia-

tion was transmitted into the exposure chamber via waveguide and a standard gain horn, Narda Model 644. A diagram of the power source and monitoring equipment is provided in Figure 1.

Field measurements were obtained with a National Bureau of Standards probe, EDM 1C, at various points within a cylindrical space corresponding to the area occupied by the torso of a sitting monkey. The area corresponding to the center of the animal's head served as a reference point for the power densities used. Additional measurements of the field in the area of the animal's buttocks were also obtained. All measurements were in the far field. From the measurements in the head area (a cylinder 5 cm high and 6 cm in diameter) the standard deviation was found to be 8.6 percent of the mean power density at 20.23 mW/cm².

The monkey was seated in a restraint chair directly below the horn. The top surface of the chair was 133.4 cm from the opening of the horn. The exposure facility has been previously described (4); a schematic of the facility is shown in Figure 2.

The restraint chair was constructed of Styrofoam in a manner similar to that used with other monkey chairs (6). Two Teflon levers protruded from the top of the chair and were within easy reach of the monkey. The chair is shown in Figure 3.

Colonic temperature was obtained by inserting a Yellow Springs Instruments' rectal probe, number 702, approximately 5 cm into the rectum of the squirrel monkey. A reference probe was located below the chair.

The exposure facility was well ventilated, and white noise of approximately 79 dB was always present in the exposure chamber. Room temperature generally varied from 22.5°C to 23.2°C between the first and last daily animal run; there was a standard deviation of 1.06°C over the entire duration of the study. Humidity typically decreased approximately 5 percent from morning to afternoon. Due to seasonal variation the average relative humidity was 57 percent during the half-hour exposures and 74 percent during the one-hour exposures.

METHOD

The monkeys were gradually deprived of food until their body weights were less than 90 percent of their free-feeding weights. When this criterion was reached, training was initiated. Training began with the restraint chair located in a sound-isolated animal chamber with white noise present. The animals were first taught to press either the right or left levers on the top of the chair to obtain a 190-mg Noyes monkey pellet which rolled down a plastic tube into the bowl-like depression on the top surface of the chair. Red and blue lights (25W) approximately 20 cm in front of the animal alternated with each lever press. After the animals consistently pressed the bars for at least three sessions the contingencies were changed so that only left lever presses during a blue light were reinforced, while right lever presses continued to alternate the color of the lights. Training progressed during the sub-

sequent sessions in various stages; each stage consisted of increasing the number of right lever responses required to produce the blue light and, hence, food availability. The end result of training was performance on a schedule in which right lever responses produced either a 0.5-sec illumination of the red light or a 10-sec illumination of the blue light. The blue light occurred on the average of once a minute (a variable interval of one minute, VI 1-min schedule) contingent on a right lever press. A left lever press during the 10-sec blue light produced a food pellet and reinstated the former condition. Left lever presses during the red light or in the absence of the blue light resulted in a 20-sec period during which right lever responses produced only the brief red light. Right lever presses in the presence of the blue light had no scheduled consequences. Initially sessions lasted one hour. The monkeys worked on the VI 1-min schedule for twelve sessions prior to being exposed to microwaves.

Beginning with session 91 and ending at session 121 the monkeys were exposed to the microwaves for 30 minutes during one-hour sessions. Power density during a session was constant but ranged from 10 to 60 mW/cm² through twenty exposure sessions. Sham exposures generally occurred on Mondays and between exposure sessions. Animals were exposed during the middle 50 percent of a session, and the first and last 25 percent were used as intrasession controls. Although the animals were first exposed to the lowest power density and last exposed to the highest power density, the order of exposure to the other power densities was not systematic.

At session 122 the monkeys were equipped with rectal probes and exposed for 30 minutes daily during one-hour sessions over the next 21 sessions. Thirteen exposures with rectal probes present occurred at power densities between 10 and 70 mW/cm². The order of these exposures varied so that exposure to low power densities occurred before and after exposure to higher power densities.

From sessions 144 to 196 the exposure period was increased to 60 minutes and the session length was increased to 2 hours. Power densities for these sessions ranged from 10 to 75 mW/cm². Table I summarizes all of the exposure conditions. Asterisks in the table indicate interruptions in the procedure. The first interruption occurred when the animals were instrumented with temperature probes and the second interruption was when the session time was extended to 2 hours. The exposure order was varied except that all of the exposures to 75 mW/cm² occurred in the final three sessions.

The experiment was conducted five days a week. The animals were transported from the vivarium to the microwave building approximately 15 minutes prior to being placed into the restraint chair. Five minutes were required to restrain the monkey, insert the temperature probe, and activate the equipment.

Table I
Procedures and Conditions of Microwave Exposure

Power Density (mW/cm ²)	Subjects N	Session Length (Min)	Exposure Duration (Min)	Exposure Sessions
10	4	60	30	4
20	4	60	30	5
30	4	60	30	2
40	4	60	30	3
50	4	60	30	3
60	4	60	30	3
10*	4	60	30	1
20	4	60	30	1
30	4	60	30	1
40	4	60	30	2
50	4	60	30	2
60	4	60	30	2
65	4	60	30	2
70	4	60	30	2
10*	3	120	60	5
20	3	120	60	4
30	3	120	60	3
40	3	120	60	3
50	3	120	60	4
60	3	120	60	2
65	3	120	60	2
70	3	120	60	3
75	3	120	60	3

(*2-week interruption between preceding series of exposures and the next series.)

RESULTS AND DISCUSSION

No obvious permanent physical changes were seen in any of the monkeys following either half-hour or one-hour exposures to microwaves.

The first sessions of half-hour exposures were conducted without rectal temperature probes; however, behavioral data from that condition were similar to data obtained when animals were instrumented with temperature probes. Although a variety of performance measures on the observing response task was obtained, only the rate of responding on the right lever consistently demonstrated a microwave effect. This effect was a slight decrement in response rate seen in overall responding or in running response rate. Figure 4 illustrates a decrease in the running response rate as a function of power density. Running rate is the response total divided by the time between the first response following food and the

next reinforcement summed over the entire exposure period. As shown in this figure the mean response rate is never greater than one standard deviation from the sham line at any of the power densities used. Nevertheless, there tended to be a greater decrement in rate as the power density increased.

The effect on response rate was also demonstrated in a different fashion, as shown in the next two figures. Frequently, whenever the microwaves came on or went off the monkeys stopped responding. This phenomenon is referred to as the "on effect" or "off effect" and was first reliably observed with the 50 mW/cm² exposures. No mechanical vibrations or audible noise were produced along with the irradiation coming on or going off. The pause when the microwaves came on, "on effect", began with animal 34 at 40 mW/cm², but the pause at the end of exposure did not consistently occur until the 70 mW/cm² level was reached, as illustrated in Figure 5. Figure 5 contains cumulative records of right lever responding during one-hour sessions and half-hour exposures for monkey 34. Response rate is indicated by the slope of the slanted line; pauses are indicated by horizontal lines. The numbers to the left of each row of records refer to the power density, and the arrows denote the half-hour microwave exposure. A correct left lever response and food delivery are shown by the hash marks on the slanted response lines. Hash marks on the horizontal lines indicate food availability (blue light). Figure 6 illustrates the same phenomenon for animal 42 except that the "off effect" began occurring at 60 mW/cm², and there were no consistent, definite pauses following presentation of the microwaves. Another effect illustrated in Figure 6 during the 70 mW/cm² exposure was the failure of the monkey to take food when it was available although he continued to make lever responses. This is shown by the lowest horizontal line beneath the cumulative record at 70 mW/cm² where the hash marks (food available) are not accompanied by hash marks (food delivered) in the response record above the line.

The temperature changes in Table II indicate the difference between temperature obtained after 15 minutes into the session and at the end of 45 minutes of the session; i.e., the middle 30 minutes of a session. The colonic temperature of the monkeys during the half-hour exposures showed regular increases beginning at 40 mW/cm². Although body temperature increased at low levels there was no substantial difference in the increases at 10, 20, and 30 mW/cm², as seen in Table II.

The body temperature during sham exposure did not reach a plateau before 30 minutes elapsed, which increased the difficulty of separating the effects of restraint from the effects of microwave exposure. The body temperature of squirrel monkeys continued to increase throughout 2 hours of restraint in a primate chair without microwave irradiation although the increases were quite small after the first 30 minutes.

Table II
Colonic Temperature Increase ($^{\circ}\text{C}$) During 30 Minute Exposures

	Power Density mW/cm^2							
	0	10	20	30	40	50	60	70
Mean	.36	.73	.65	.68	.96	1.34	2.28	2.73
SD	.27	.18	.19	.15	.18	.25	.58	.62

When the monkeys were irradiated for 1 hour, the exposure period began after the animal had been restrained for 30 minutes. Under these conditions, the temperature increases during the lower power densities ($40 \text{ mW}/\text{cm}^2$ and below) were less than for the 30-minute exposures and are consistent with the observation that the rate of temperature increase due to restraint alone is greatest during the first 15 to 30 minutes. Therefore, the component of the temperature increase due to restraint is less for the one-hour exposure session than for the 30-minute exposure session. Figure 7 illustrates colonic temperature rises in three squirrel monkeys after one-hour exposures to various power densities. The temperature is logarithmically scaled on the ordinate, and each point represents the mean of several exposures for each animal. These increases represent the difference between temperatures obtained after 30 minutes into the session and at the end of 90 minutes of the session; i.e., the increase during the middle 60 minutes. As seen in Figure 7, body temperature increased with increases in power density although a major inflection is seen between 40 and $50 \text{ mW}/\text{cm}^2$. It may be that the temperatures below $50 \text{ mW}/\text{cm}^2$ represent temperature increases to which the animals were able to equilibrate. The power densities, $50 \text{ mW}/\text{cm}^2$ and greater, probably produced a heat load that the animals could not dissipate within the one-hour exposure.

Another view of the temperature rises during one hour exposures is shown in Figure 8 for monkey 26. The figure illustrates that monkey 26 could easily tolerate the temperature increases during exposures to less than $40 \text{ mW}/\text{cm}^2$. At $50 \text{ mW}/\text{cm}^2$ the increases tended not to be stabilized, and at $75 \text{ mW}/\text{cm}^2$ lethal temperatures were approached. However, at $75 \text{ mW}/\text{cm}^2$ this animal stopped working the lever when his body temperature surpassed 42.0°C , and this extensive pause was accompanied by a temperature decrease.

Although the animals tended to adapt to the microwaves with repeated exposure, none of them could compensate for the large temperature increases when exposed to $75 \text{ mW}/\text{cm}^2$. To prevent the possible death of an animal due to high temperature the radiation was turned off whenever colonic temperature exceeded 42.5°C . Such high temperatures occasionally occurred.

Figure 9 contains cumulative response records and temperature records of the three squirrel monkeys during typical sessions whenever they were exposed to 74 mW/cm^2 . As seen in this figure the microwaves were turned off for monkey 42 at 72 minutes into the session because of his high colonic temperature. The disruption of responding with both initial and continued exposure is obvious in the records of monkeys 42 and 34. In addition, there was a pronounced cessation of responding in all three animals when the microwaves were turned off. Monkeys 42 and 26 missed many opportunities for reinforcement even though the animals continued responding.

The general behavioral effects of one-hour exposures to the microwaves were quite similar to those of the half-hour exposures but were more pronounced. No consistent changes in behavior occurred at levels below 50 mW/cm^2 , and above that level the effects increased with increases in power density. The cumulative records of right lever responding best illustrate the behavioral disruption. For example, the decreasing slope of the cumulative response record in Figure 10 shows a deceleration in response rate for monkey 26 during microwave exposure beginning at 60 mW/cm^2 . When the microwaves went off, pauses were first observed at the 65 mW/cm^2 level, and the frequency of pauses increased at higher power densities. Following these pauses the response rates gradually returned to normal and became greater than the response rates prior to turning off the irradiation. Although some rate changes and even pauses occurred at other times, as seen in the records at 20 and 30 mW/cm^2 , these changes were not related to the introduction or removal of the microwaves.

The monkey with the highest response rate, monkey 42, demonstrated similar response rate changes as a result of microwave exposure. Figure 11 contains typical cumulative records of monkey 42 at the various power levels. Pauses were first seen at 60 mW/cm^2 following the removal of the microwaves. Again, there was a decreased rate during exposure followed by partial recovery after the microwaves were turned off. The rate changes first appeared at the 40 mW/cm^2 level but were much more obvious at the higher power densities. As with monkey 26, no pauses occurred when the microwaves were turned on.

A different effect was seen in the behavior of monkey 34 and is illustrated in Figures 12 and 13. Figure 12 contains cumulative records of right lever responding and Figure 13 shows left lever responding during the exposures at various power densities. Occasionally this animal would spuriously respond on both levers simultaneously, precluding reinforcement as seen on the 20 mW/cm^2 record of Figures 12 and 13. However, this seemed to be unrelated to microwave exposure as it occurred during sham sessions also. The rates were lower at 20, 30, 40, and 50 mW/cm^2 , but such rate decreases covered the entire sessions. An interesting aspect of these figures is that while nothing obvious occurred at 40 mW/cm^2 and below, the response rate on both levers gradually began to increase during exposure starting at 50 mW/cm^2 . The right lever response rate at 75 mW/cm^2 is even greater than under sham conditions. Pauses at either the beginning or end of microwave exposure were first observed at 50 mW/cm^2 , but consistent pauses at both beginning and end of exposure were only

seen at 75 mW/cm². After the microwaves were turned off responding on both levers generally returned to normal in those cases where it had changed.

The general effect of microwave irradiation in most animals was to decrease response rate during and after exposure. However, the higher power densities produced an increase in rate for monkey 34. This effect is better illustrated in Figure 14 where the overall response rate during exposures for monkey 34 at 65, 70, and 75 mW/cm² is shown to be well above the sham rate. Monkeys 26 and 42 decreased their response rates regularly at levels greater than 40 mW/cm².

Although response rates were not reliably affected during exposure, the overall right lever response rate did show a consistent relationship to power density during the half-hour period following exposure, as illustrated in Figure 15. All three animals had lower response rates at the higher power densities during this post-exposure period, and the effect tended to increase with increases in power density. This effect was not merely due to the pause at the end of irradiation because the identical relationship was evident in running response rate.

Behavioral changes other than right lever response rate were less reliably influenced by the microwave exposure. For example, Figure 16 illustrates the latency of an animal's response on the food lever when food availability was signaled during the one-hour exposure period (reinforcement reaction time). Although no large differences from the control sessions (indicated by 100 percent) occurred below 50 mW/cm², monkey 42 showed large increases in reinforcement reaction time from that point on, while the reaction time of monkey 26 began increasing at 40 mW/cm² and continued up to 70 mW/cm². The return to baseline at 75 mW/cm² for monkey 26 has no explanation at present. The reinforcement reaction time of monkey 34 was not affected until exposed to 75 mW/cm².

One other effect, obvious in only monkey 34, was that the number of incorrect left lever responses reliably increased with increases in power densities. When the ratio of incorrect left to right lever responses is plotted, the differential increase in number of incorrect responses for monkey 34 is dramatic, as illustrated in Figure 17. Monkeys 26 and 42 also tended to increase their incorrect responses during exposure to the higher power densities, but the effect showed less consistency than that for monkey 34.

Several additional behavioral indices such as post reinforcement pause time and left lever response rate were examined. However, none of these showed consistent effects. On the other hand, observations via the television monitor confirmed earlier reports of emotional behavior possibly caused by the extraordinary heat load at 70 and 75 mW/cm². The monkeys would move within their restraint chairs quite excitedly, raising their arms, closing their eyes, gnawing on the chair, and occasionally becoming comatose until 5 or 10 minutes had elapsed with the microwaves removed. One animal, 20, when first irradiated at 70 mW/cm² produced a colonic temperature of 43.6°C after about 25 minutes of exposure even

though the normal baseline temperature of monkey 20 was not any higher than the normal temperatures of the other animals. He foamed at the mouth and began jerking in a convulsive manner. He was immediately removed (his entire body felt warm at this time) and wrapped in cold water sponges. Within 30 minutes his temperature returned to 40.3°C and he behaved normally. Upon his next exposure (65 mW/cm^2) he frothed at the mouth but continued working. Further exposures of this animal to 65 and 70 mW/cm^2 did not have as great an effect although frothing and excitable behavior still occurred. None of the other monkeys reached such high body temperatures even when exposed for 1 hour.

CONCLUSIONS

Obviously the behavioral changes seen in the present experiment are directly related to hyperthermia in the squirrel monkey. Only in those cases where colonic temperature increases exceeded 1°C was behavior consistently affected. Although there were slight indications that one of the monkeys could detect the onset of the 40 mW/cm^2 exposure, the other animals demonstrated no such ability until 50 mW/cm^2 or greater power densities were used. Colonic temperature increases always exceeded 1°C at 50 mW/cm^2 regardless of duration. While it is possible that the temperature data were confounded by the use of a metallic temperature probe, it is unlikely since the probe was well shadowed by the torso of the monkey between the probe and the horn.

Another rather obvious phenomenon in the present study is the relationship between removal of the microwaves and cessation of lever responding. This relationship was also first observed at 50 mW/cm^2 . The data indicate that turning off the irradiation was a much stronger stimulus event than turning the microwaves on. No doubt this is because of the differential rate of change in colonic temperature. In most instances the temperatures of the monkeys dropped twice as fast as they had increased. Considering that the animals were restrained and could only utilize peripheral vasodilation and sweating of their extremities for heat loss, the blood flow to the superficial tissues of the hands and feet must have been greater than normal (1). Such variations from normal blood flow would probably be greatest when the microwaves were turned off and could possibly account for the cessation of lever responding at that time.

The idiosyncratic responding by the monkeys emphasized that reported findings of increases or decreases in average response rate may be species specific. Since our animals frequently stopped responding for awhile during exposure and invariably resumed responding, we illustrate a deficiency in using "work stoppage" as a measure of microwave effects. Although a consistent decrement in response rate occurred following exposure, I am convinced that the effect is more related to a rate of body temperature decrease than it is to microwave exposure per se.

These results also illustrate that the effect of 2450 MHz microwaves is probably of a temporary nature. When the exposure conditions

were removed, the squirrel monkeys generally recovered previous response rates, regardless of the direction of change. This finding agrees with the results of our rhesus study (2). Another agreement with the rhesus study was in the tendency of the squirrel monkeys to be less affected behaviorally with repeated exposures to microwaves. On the other hand, there was no definite tendency for the body temperatures to adapt to repeated exposure as was seen in the rhesus experiment.

The information obtained in the present study provides further support for constructing a scale of microwave-induced behavioral effects based on body mass. The threshold for behavioral effects in squirrel monkeys appears to be 40 and 50 mW/cm² for a one-hour exposure to 2450 MHz. This threshold is 10 to 20 mW/cm² lower than that proposed for the rhesus on the same task. between

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DIAGRAM OF MICROWAVE POWER SOURCE AND MONITORING EQUIPMENT

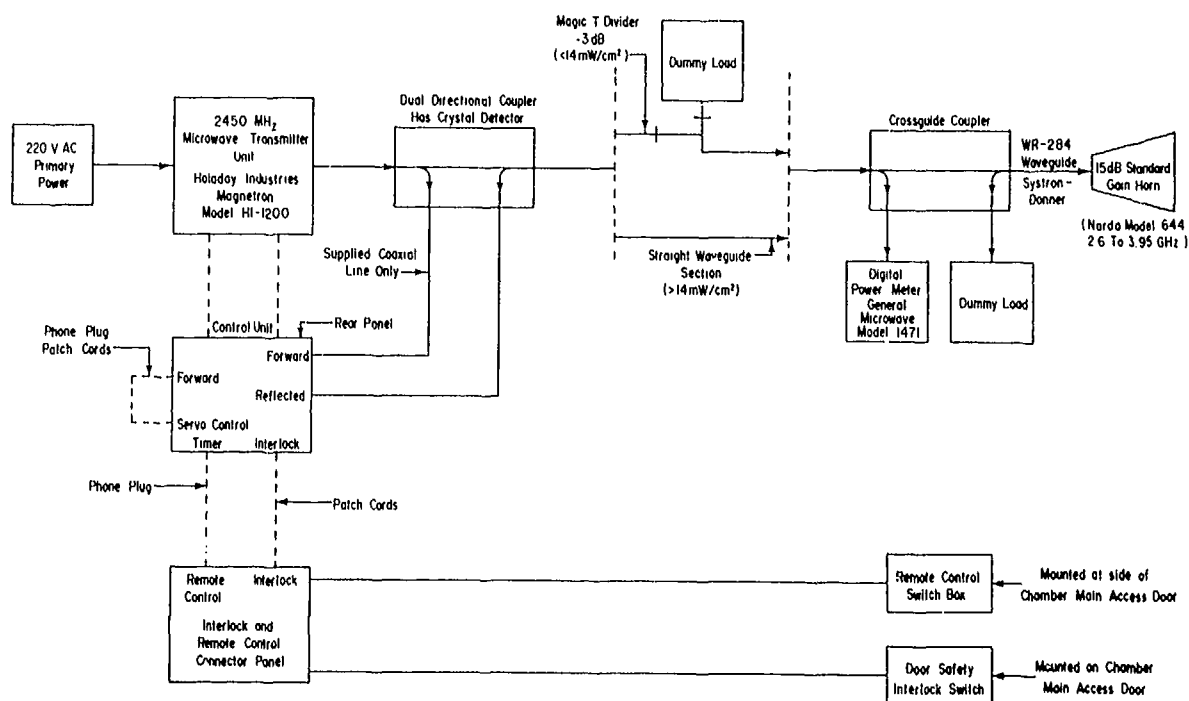


Figure 1. Schematic diagram of the microwave power source and control equipment. The horn was mounted above the animal and the transmitter unit cycled to 120 pulses per second.

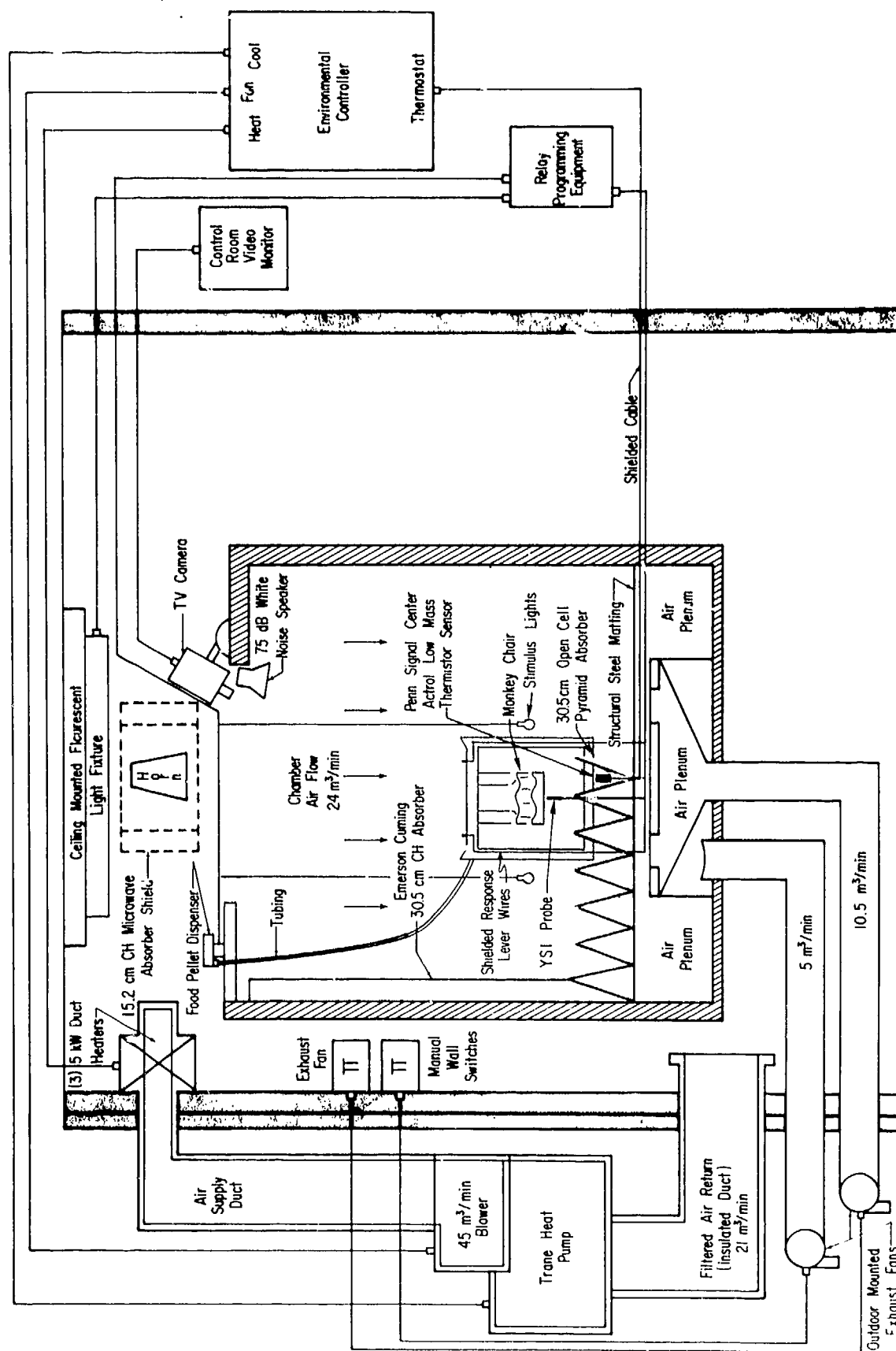


Figure 2. Diagram of the exposure chamber and ventilation system.

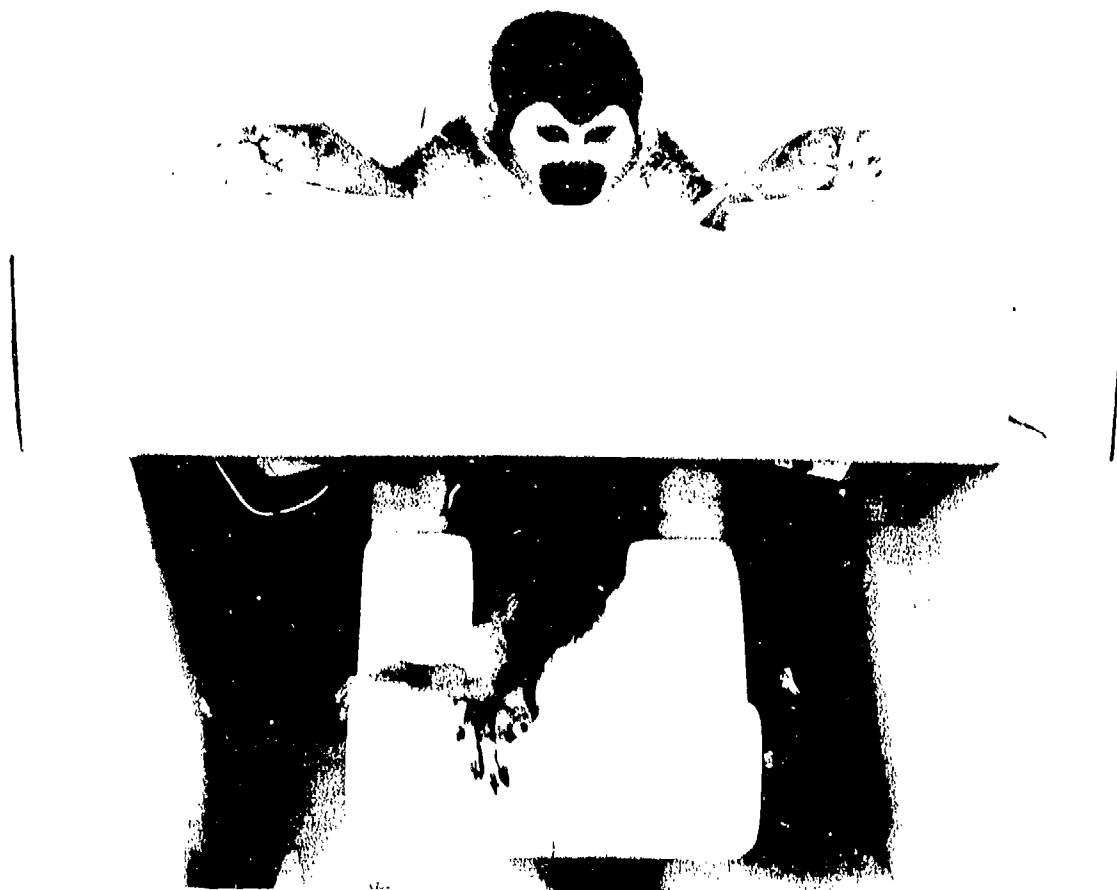


Figure 3. A squirrel monkey sitting in the restraint chair with its hands on the two Teflon levers. Insertion of the temperature probe was via a defecation aperture in the seat. The food delivery tube (not shown) was inserted beneath the plastic strap next to the lever on the right.

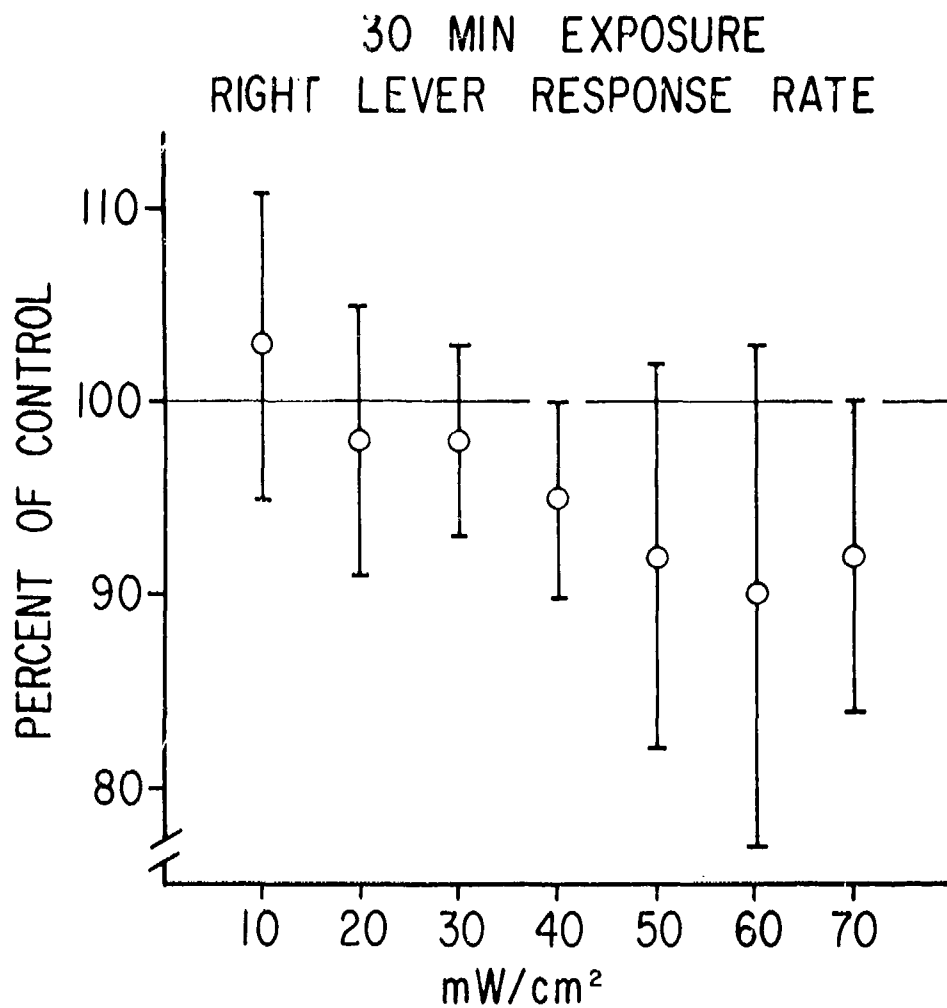


Figure 4. The ratio of running response rate on the right lever during 30-min exposure sessions to control sessions. The horizontal line at 100 denotes the no-difference ratio. The circles represent the means of four monkeys and the vertical bars represent the standard deviations. The power density is indicated on the abscissa.

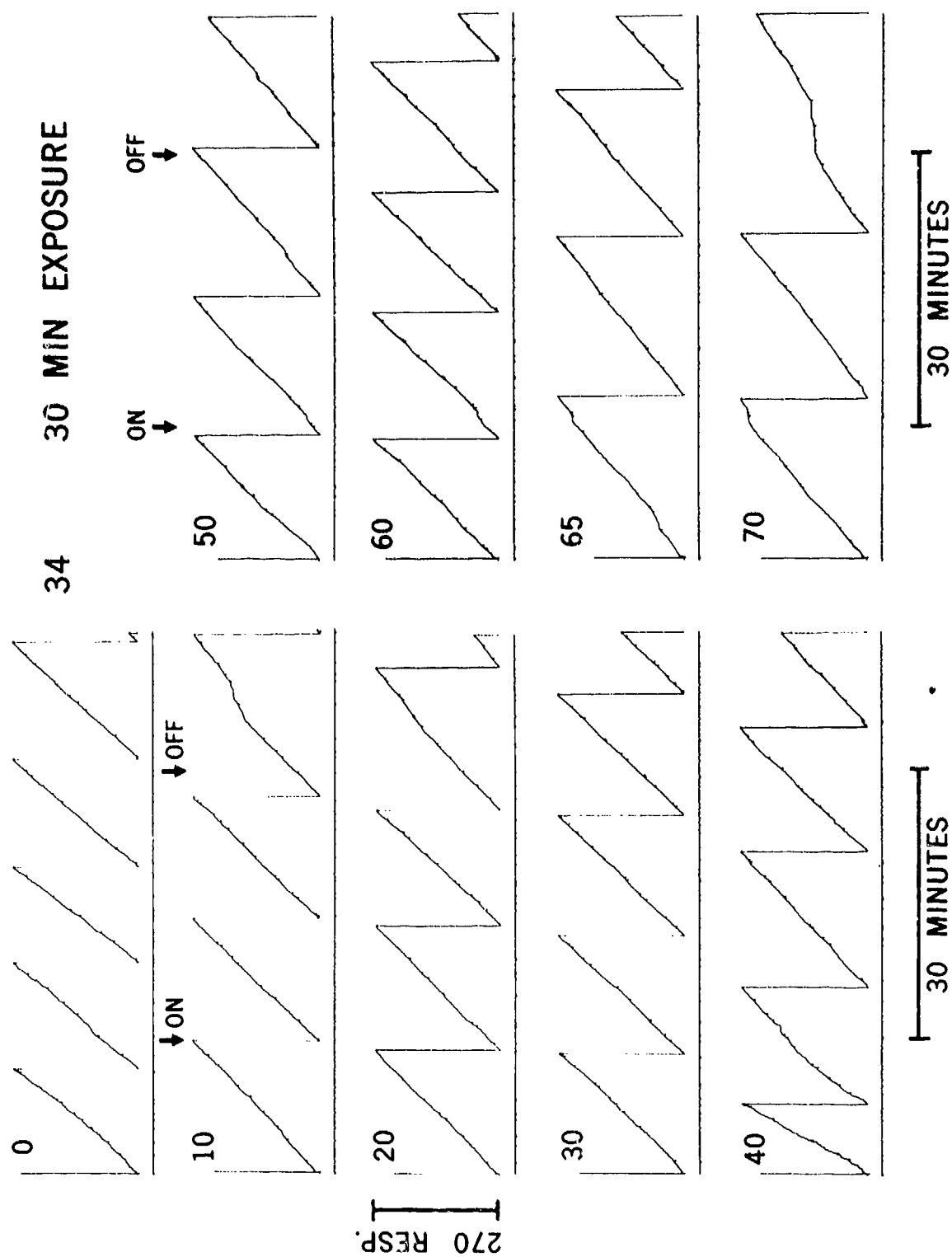


Figure 5. Representative cumulative records of monkey 34's right lever responding during 30-min microwave exposures at power densities shown in the upper left of each record. (See text.)

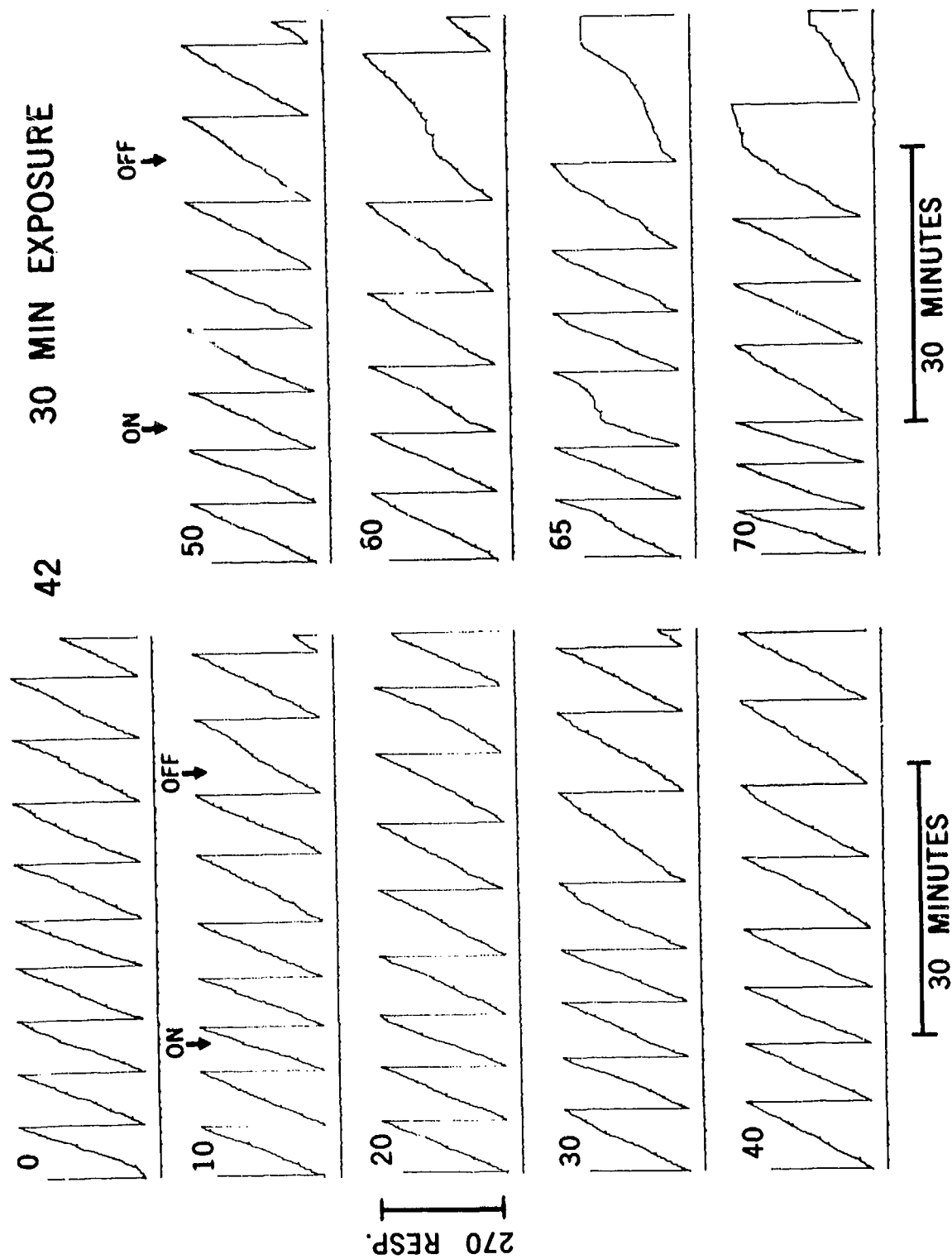


Figure 6. Cumulative records of right lever responding for monkey 42. The greater the slope of the record, the greater the rate of responding. At 270 responses the pen resets. (See text.)

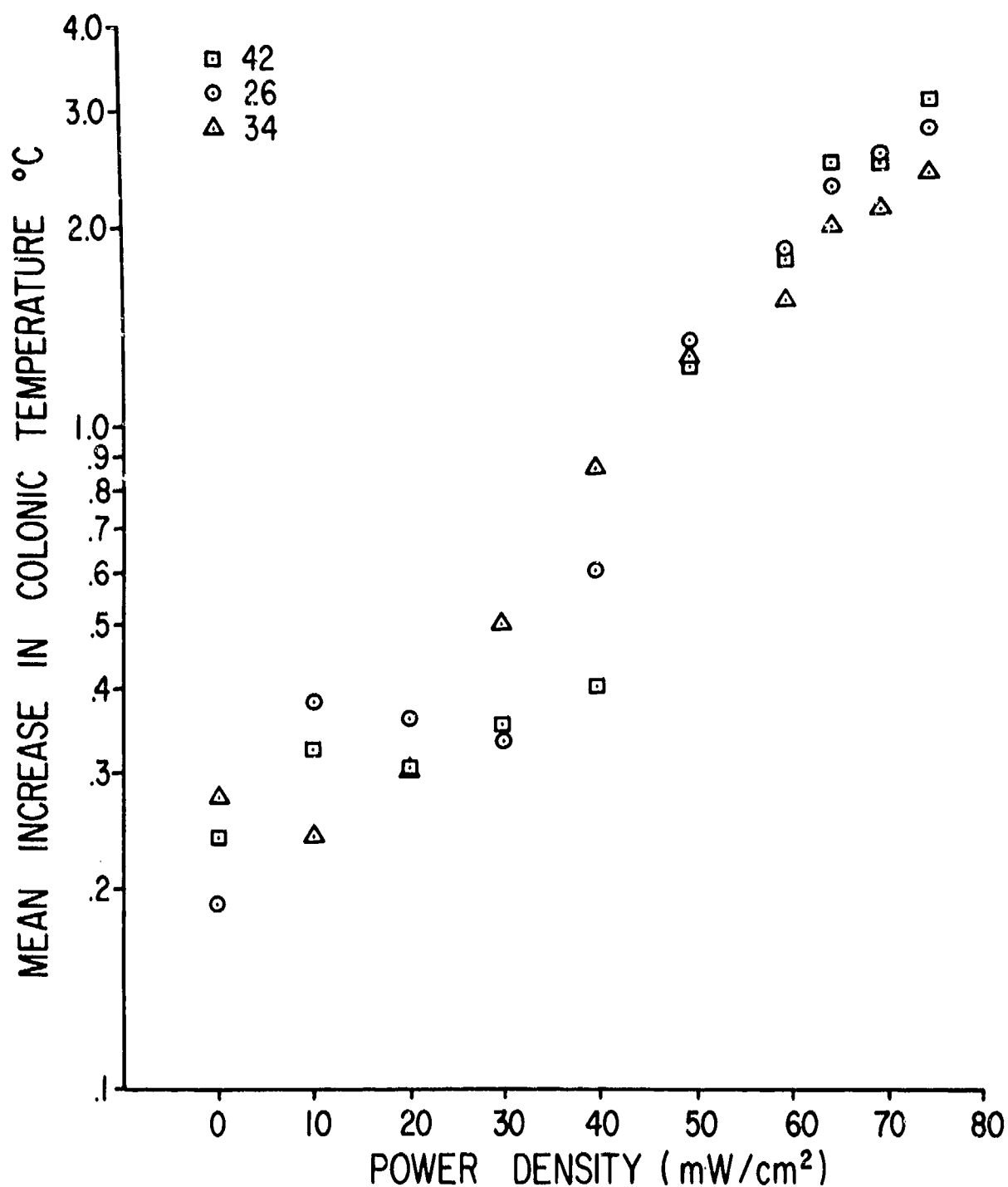


Figure 7. The mean increase in colonic temperature as a function of power density for the three squirrel monkeys exposed for 60 min. The temperature scale is logarithmic, and 0 on the abscissa denotes the sham condition. The numbers and respective symbols denote the three different monkeys.

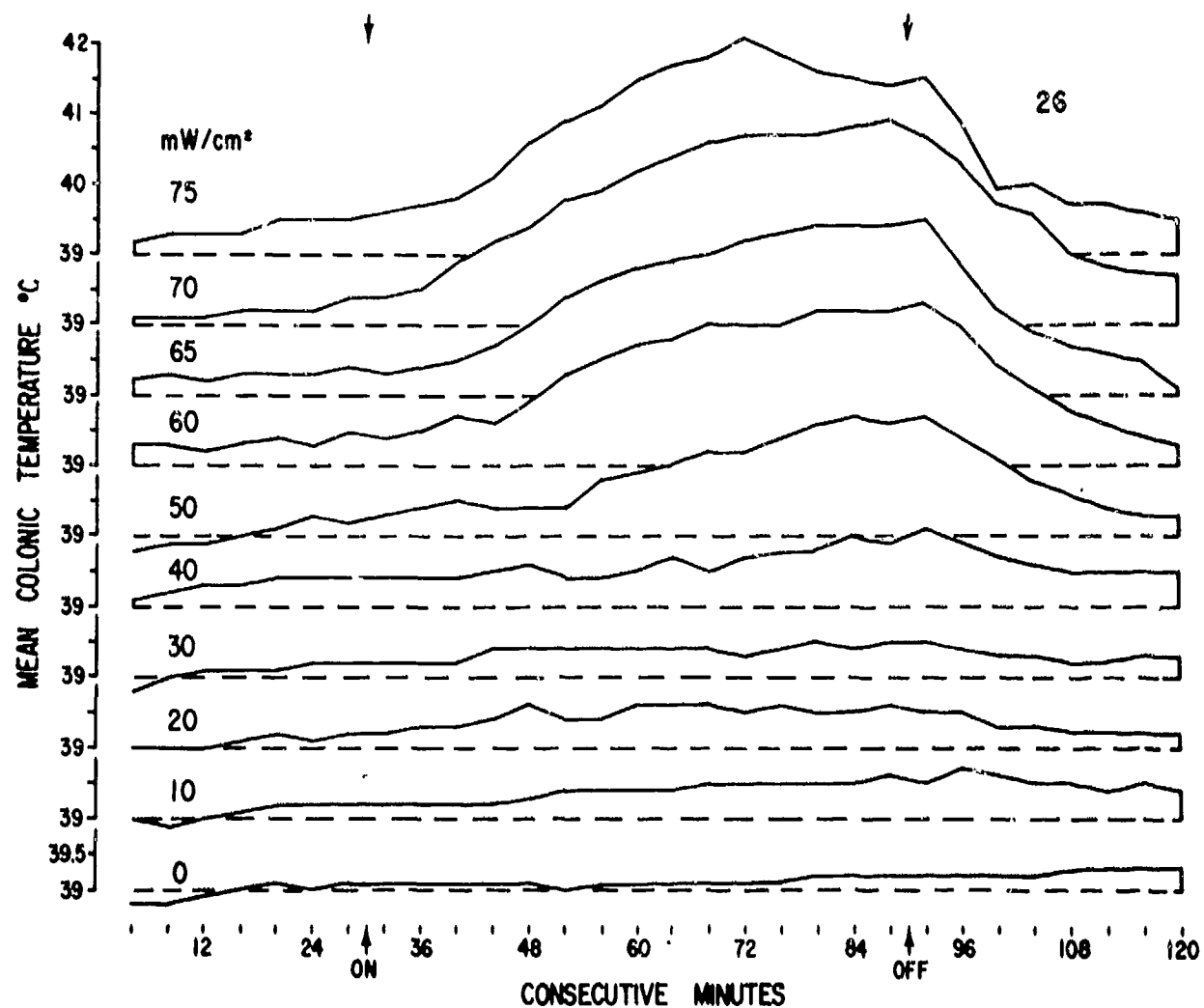


Figure 8. Typical temperature records of monkey 26 during complete 2-hour sessions. Arrows indicate when microwaves began and ended. Power density is shown on the left, and colonic temperature is indicated in 0.5°C increments on the ordinate. The dashed lines represent 39.0°C at each exposure level. Sessions began at the left.

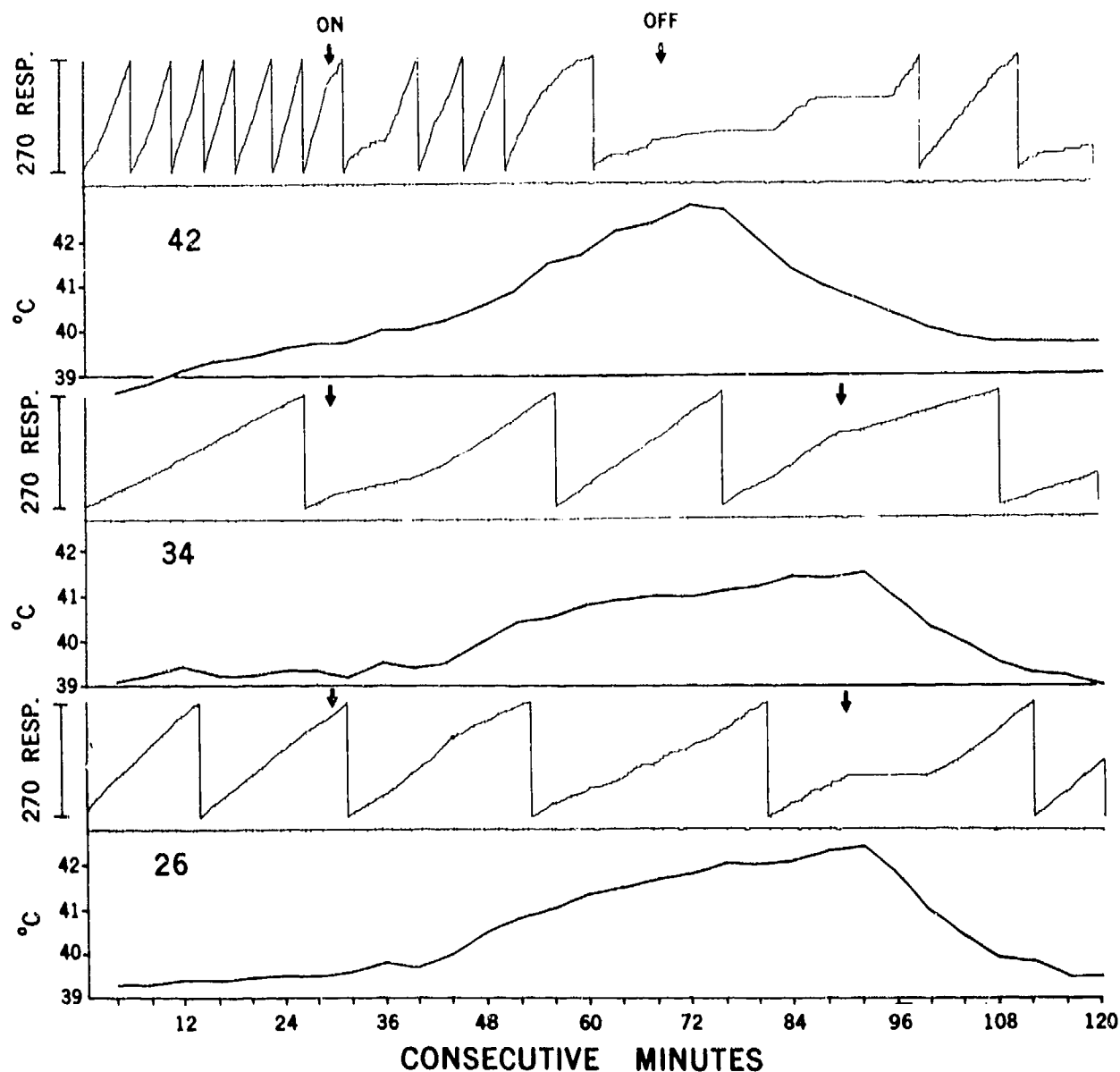


Figure 9. Simultaneous cumulative response and temperature recordings of entire 2-hour sessions for three monkeys exposed to 75 mW/cm². Arrows indicate when exposures began and ended. The large numbers on the left identify the animal and each pair of records; cumulative response above, temperature below. The lower horizontal line below the response record denotes when food was available. Response frequency and colonic temperature are shown on the ordinate and consecutive 4-min blocks are shown on the abscissa.

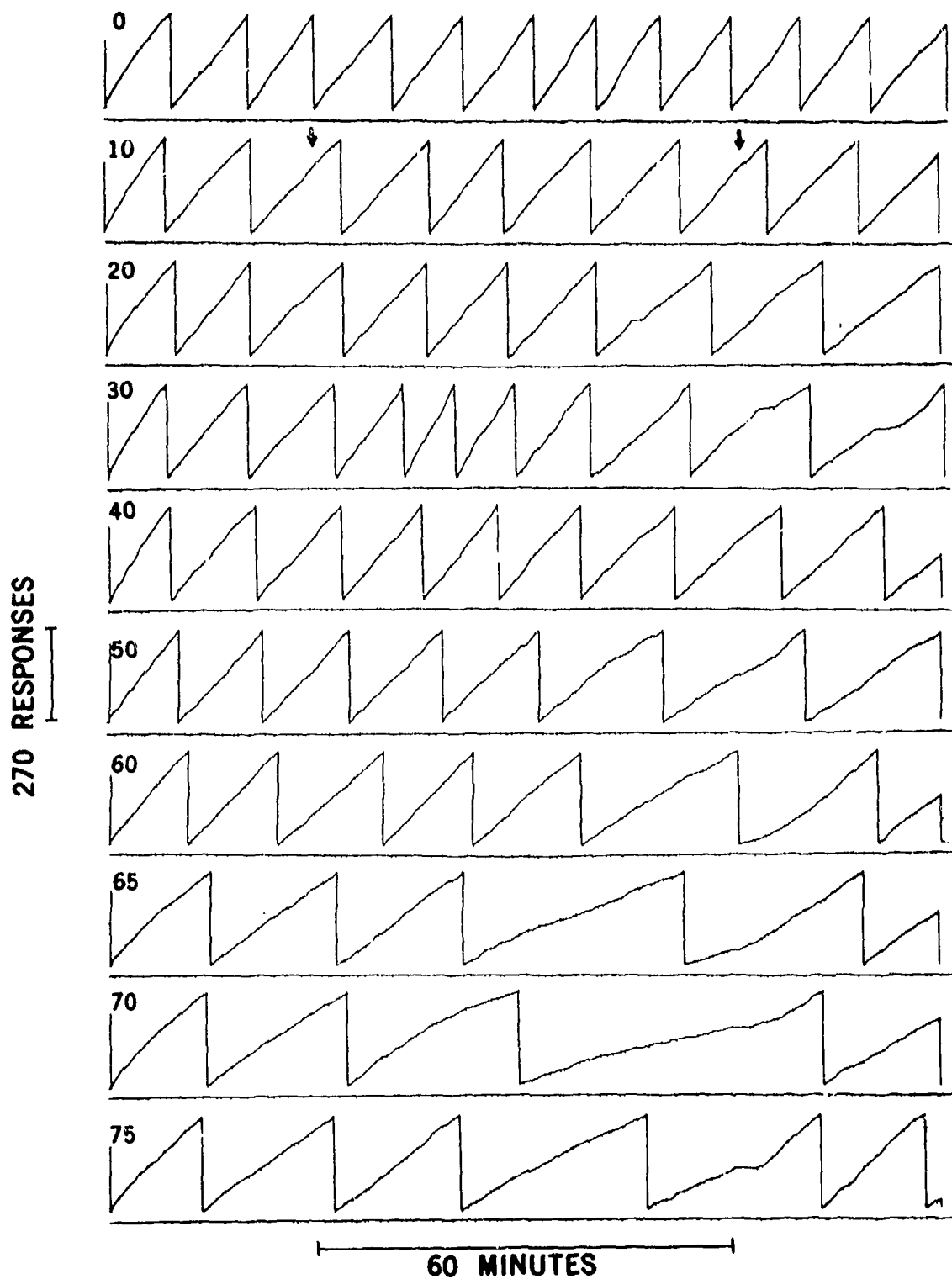


Figure 10. Representative cumulative records of right lever responding for monkey 26. Power densities are indicated on the left. Arrows refer to beginning and end of microwave exposure.

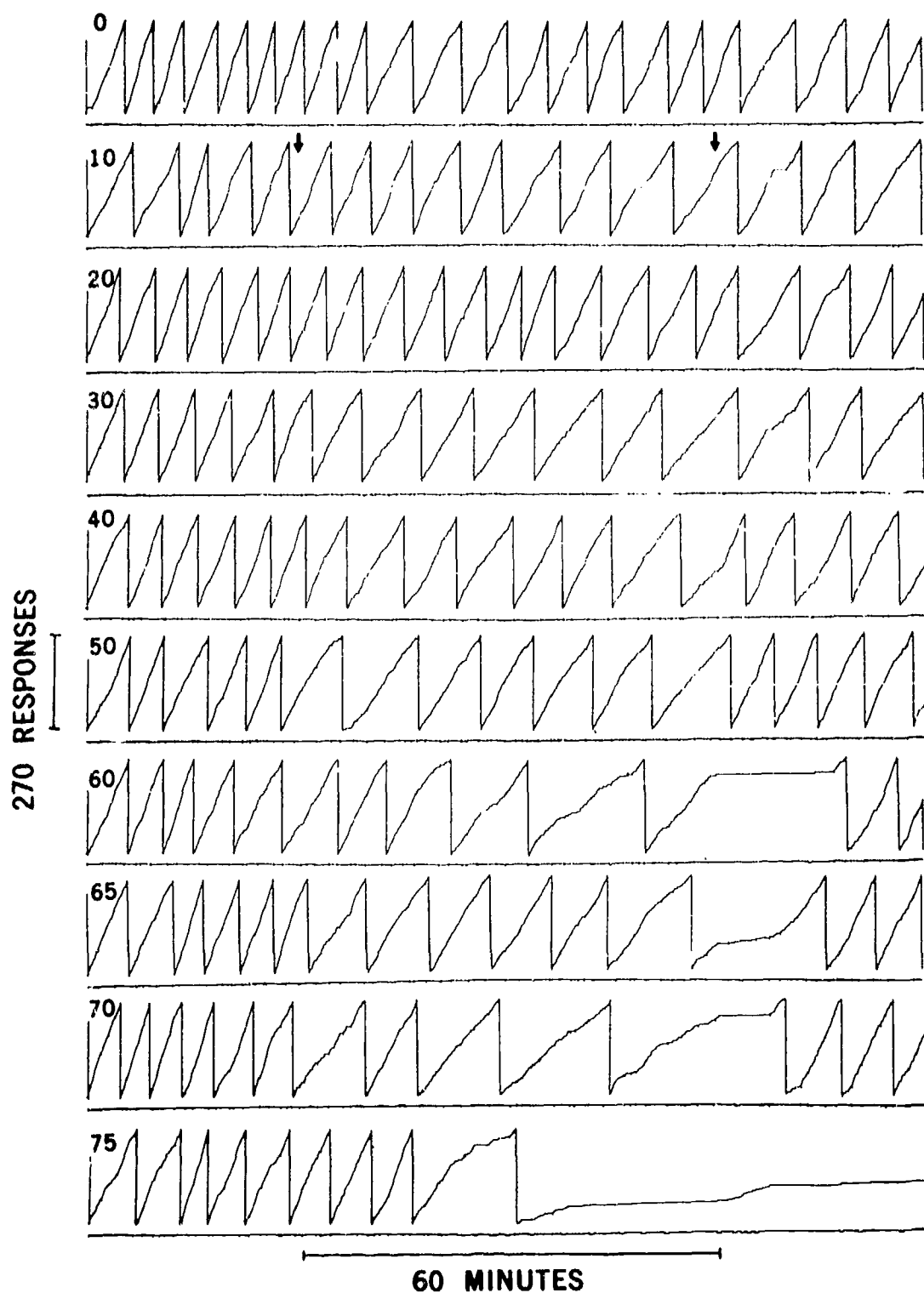


Figure 11. Cumulative records of monkey 42's right lever responding. Hash marks on the cumulative response lines denote food delivered and deflections on the horizontal lines indicate food availability. Power densities are at the left; arrows mark beginning and end of microwave exposure.

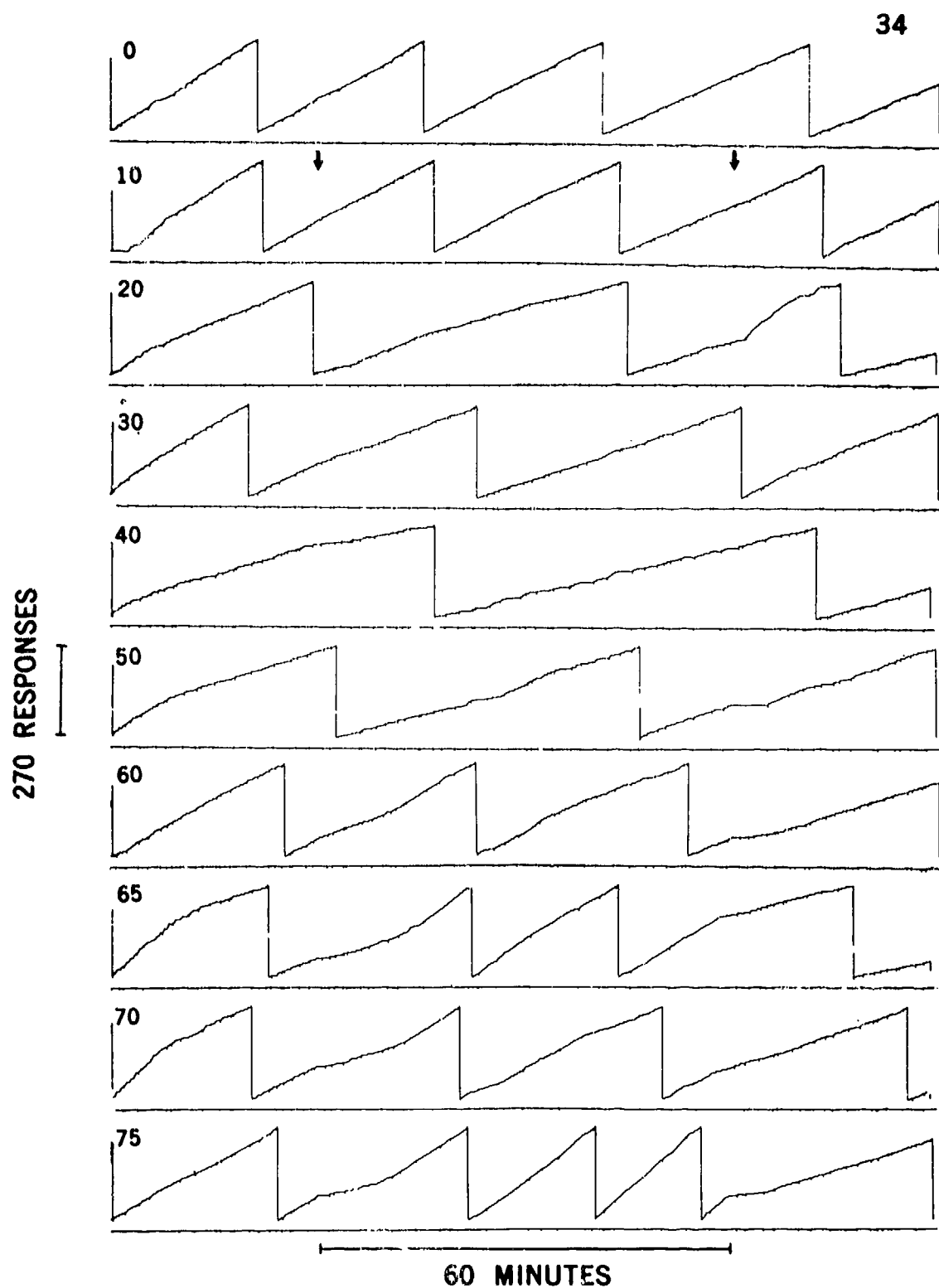
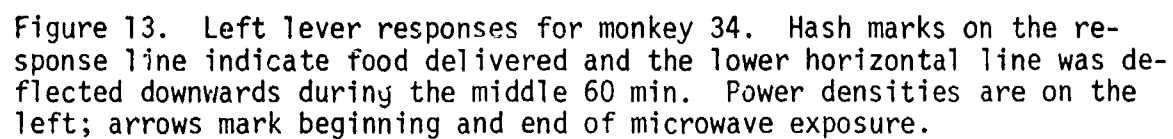


Figure 12. Cumulative records of monkey 34's right lever responding. Power densities are on the left; arrows mark beginning and end of microwave exposure.

34



RIGHT LEVER RESPONSE RATE

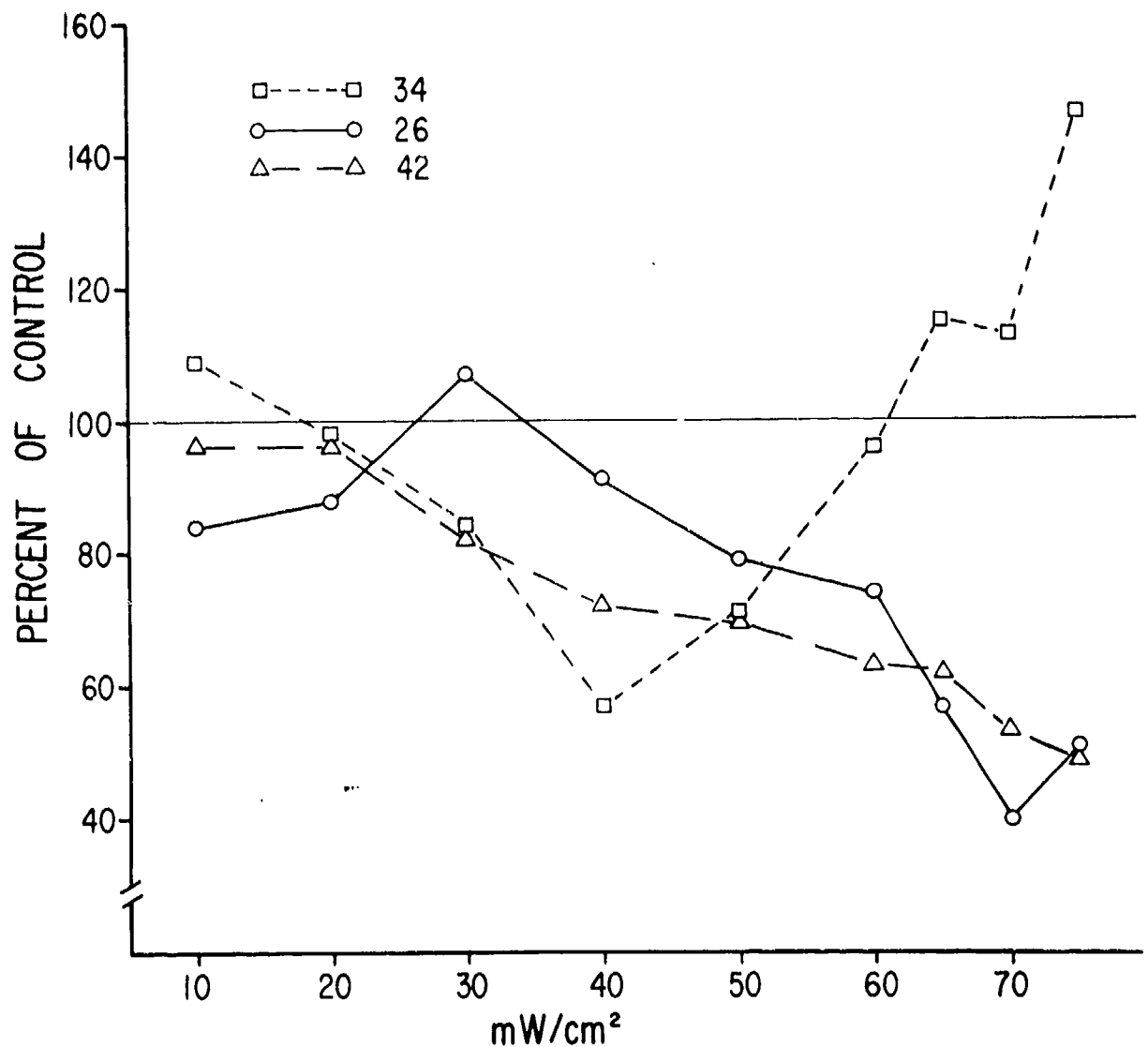


Figure 14. The ratio of response rates on the right lever during exposure sessions to right lever response rates during control sessions. These ratios represent the overall rates of responding while being exposed for 60 min. The line at 100 percent denotes the no-difference ratio when comparing exposure to sham conditions. The symbols refer to the three monkeys as identified in the upper left of the figure.

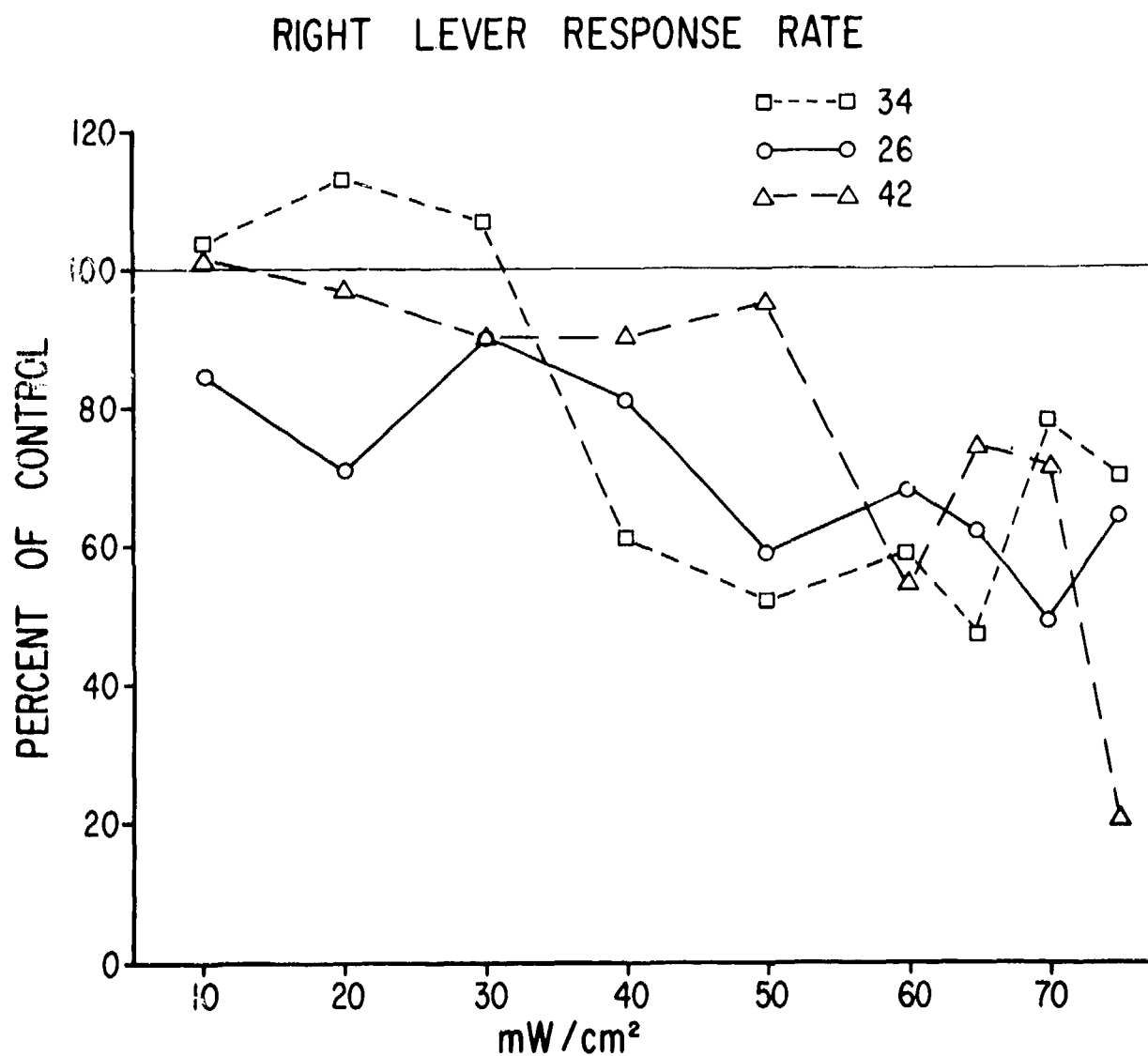


Figure 15. The ratio of overall right lever response rate, during the 30 min following the end of irradiation, to the response rate during the same period in sham sessions. The 100 percent line indicates no difference between sham and exposure conditions.

REINFORCEMENT REACTION TIME

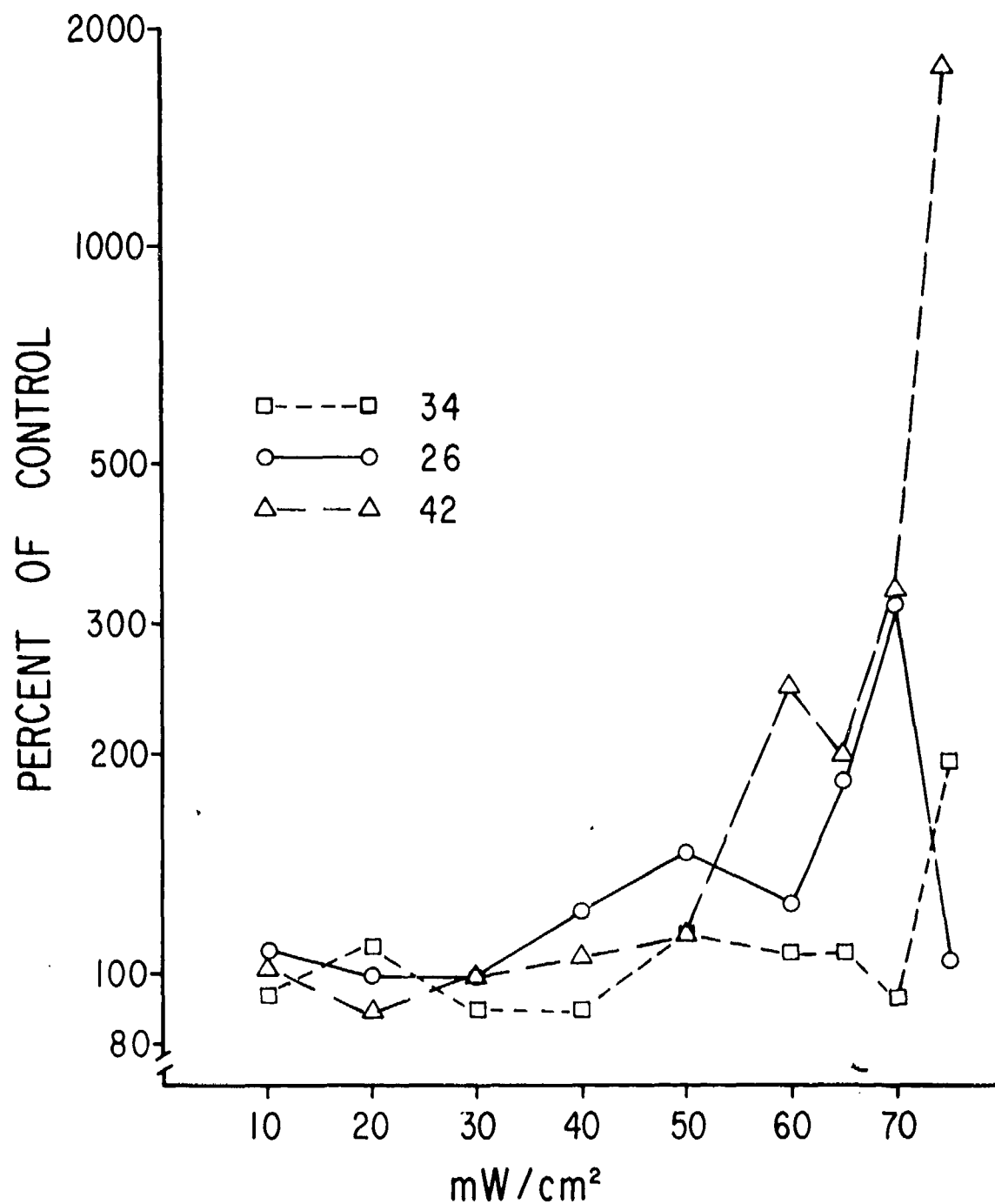


Figure 16. The ratio of latency to respond on the left lever when food was signaled during exposure, compared to sham sessions. The ordinate is a logarithmic scale, and 100 percent indicates no difference between exposure and sham conditions during the 60-min exposure period.

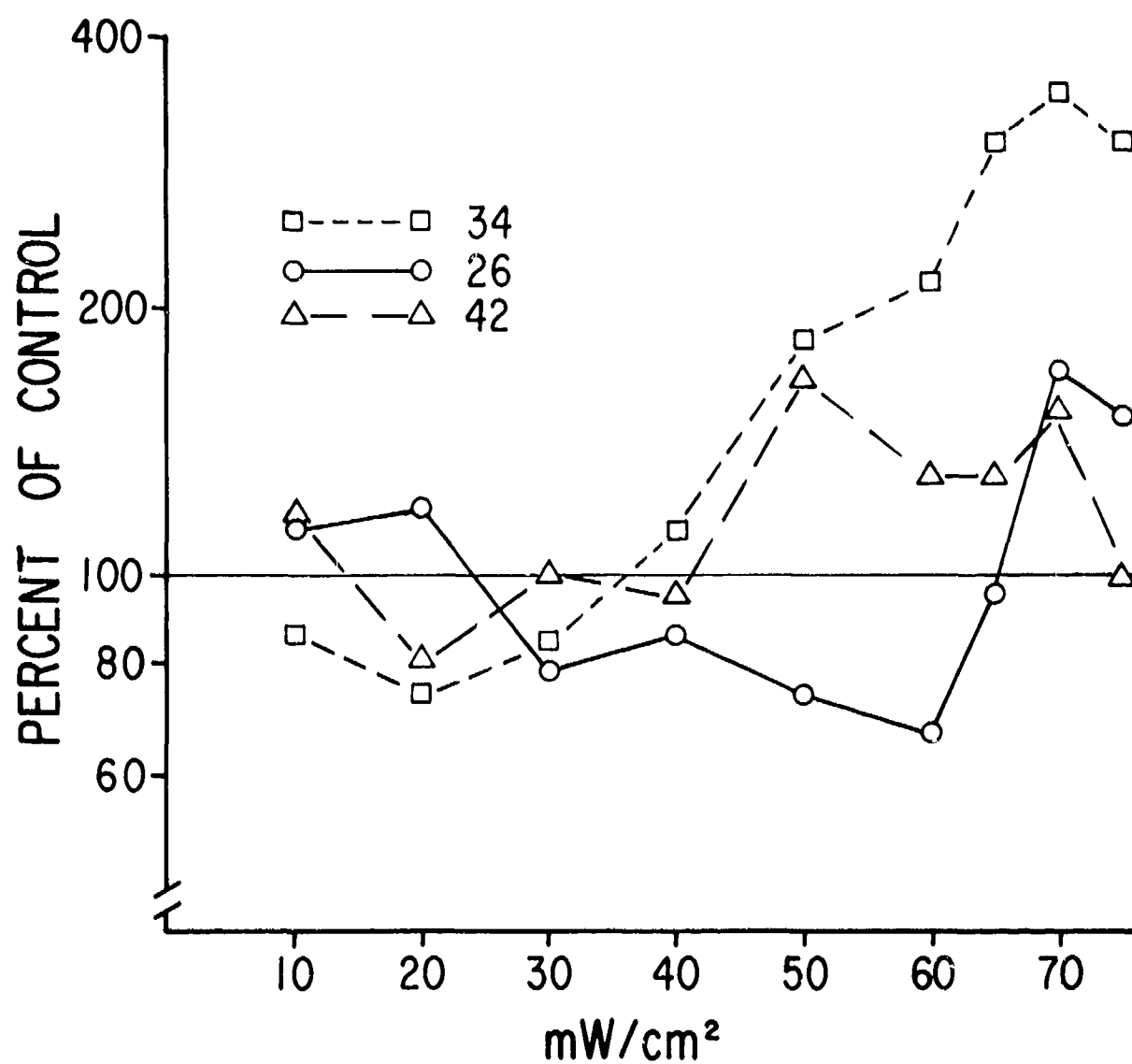


Figure 17. The ratio of incorrect responses on the left lever to right lever responses during the 60-min exposure periods compared with the same ratio during similar periods of sham sessions.

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microwaves.

The behavior of squirrel monkeys on a vigilance task was disrupted by 30- or 60-minute exposures to 50 mW/cm² and higher power densities. This disruption increased with the increase in power density. Under both durations of exposure, behavior was not consistently perturbed until colonic temperature changes exceeded 1°C. Colonic temperatures regularly increased beginning at 10 mW/cm² and were related in a nonlinear fashion to the power density with a marked acceleration between 40 and 50 mW/cm².

* Sq. cm.

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