Longevity of Microwave-Treated (2.45 GHz Continuous Wave) Honey Bees in Observation Hives[1]

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ABSTRACT

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Adult honey bees were exposed for 30 min to 2.45 GHz of continuous wave microwave radiation at power densities ranging from 3 to 50 mW/cm². After exposure, bees were returned to glass-walled observation hives, and their longevity was compared with that of control bees.

No significant differences were found between microwave- and sham-treated bees at any of the power densities tested.

A system of solar power satellites (SPS) has the potential for providing the United States with a large share of its electric energy needs in the first quarter of the 21st century (Glaser 1980). Satellites would be in geosynchronous orbit above the earth, collect solar energy, transport this energy to earth via microwave beams, and convert it to electricity at receiving antennae (rectennae) ca. 10 km in diameter. The Department of Energy and the National Aeronautics and Space Administration have conducted a feasibility study to assess the possible impact of this far-reaching technology (Koomanoff and Sandahl 1980). The leaders of this program have pursued aggressively a program to elucidate any potential economic, societal, environmental, or engineering impact that would be sufficiently serious to cause abandonment of this project.

One major environmental concern is that airborne biota, including invertebrates and birds, cannot be fenced out of rectennal areas and would therefore be exposed to 2.45 GHz of continuous wave microwave (CWM) radiation at levels from 1 mW/cm² at the outer edge to 23 mW/cm² at the center. This study is part of a research program initiated specifically to determine the health and safety of invertebrates that would be found within and surrounding rectennae. Although initial studies involve only the honey bee, *Apis mellifera* L., the overall research plan includes additional invertebrate species (Gary and Westerdahl 1978).

Engineering theory predicts that small invertebrates should not be affected by CWM because they are nearly "invisible," owing to the wavelength (12.5 cm) utilized by the SPS system. However, the complexities of biological systems dictate that experiments be conducted to determine if there are, in fact, any detectable biological effects.

The honey bee was chosen for initial experiments for many reasons, e.g.: (1) it is a flying invertebrate that ranges far from its nest and cannot be excluded from the rectennae; (2) large numbers can be studied for the duration of their short life cycle; (3) highly stereotyped behavioral patterns can be analyzed and are expected to provide a bioassay system that is more sensitive to microwave radiation than genetic, biochemical, or physiological systems; (4) honey bees are sensitive to various forms of electromagnetic radiation (e.g., Altmann and Warnke 1976, Greenberg et al. 1978, Paul and Warnke 1975); and (5) honey bees are an economically important species by virtue of pollinating crops that account for ca. one-third of the food production in the United States.

The primary objective of this study is to determine if the longevity of honey bees is altered by short-term exposure to CWM.

Materials and Methods

The experiment was conducted as a 5 × 5 × 2 + 1 factorial in a Latin square (5 by 5) with the factors being five colonies, five treatment levels (3, 6, 9, 25 and 50 mW/cm²), two exposure chambers (microwave and sham), plus an additional control held within the laboratory. There were 50 bees per treatment group. All microwave exposures were for 30 min. The longevity of treated bees was determined by posttreatment survival of bees in glass-walled observation hives (Gary and Lorenzen 1976) (Fig. 1) where intranest observations were possible without interfering with normal colony activities. Each hive contained a queen and ca. 7,000 workers on two brood and two honey combs (comb size, 20 by 43 cm). A runway from each hive extended through the laboratory wall to the outside, allowing bees to forage normally.

On each of 5 consecutive days (30 July to 3 August 1979), all bees were removed from one of the hives and released in a small, darkened room on a platform abutting a vertical glass window with natural backlighting, the sole source of illumination. Bees were highly attracted to the glass surface, where they were sampled randomly and placed in pairs in 8-mesh wire cylindrical cages (2.5 by 10 cm). After sampling, the remaining bees were returned to their hive. The confined bees had access to food (fondant of invert sugar and water) and water throughout the experiment, except during the 30-min treatment period. Caged bees were narcotized by exposure to carbon dioxide for 20 sec to permit a numbered, plastic identification tag to be glued to the thorax (tags manufactured for bees by Chr. Graze KG, 7056 Weinstadt-En-

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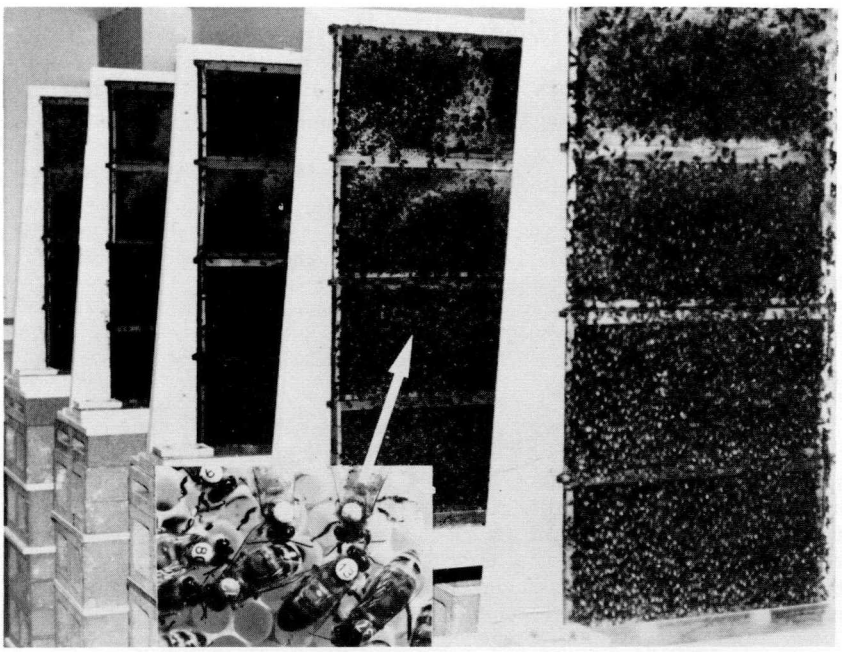

FIG. 1.—Five glass-walled observation hives, each containing microwave-treated, sham, and laboratory control bees in a population of ca. 7,000 bees. Portholes through the laboratory wall permitted normal foraging. Inset shows experimental bees identified by numbered plastic tags glued to the thorax.

dersbach, West Germany). For this study, the normal series of 500 numbers, composed of five base colors containing 100 numbers each, was extended to 2,750 by the addition of various colored dots of Pactra Aero Gloss Hot Fuel Proof Dope (Pactra Industries, Inc., Los Angeles, Calif.) applied to the tag edge. Immediately after tagging, each bee was placed in one of five compartments (2 cm diameter, 0.7 cm deep) in a rectangular (13 by 2.5 by 1 cm) styrofoam exposure cage covered with fiber glass screen (eight threads per cm) secured with six rubber bands spaced at intervals along the cage.

Ten cages of bees were assigned randomly to each of the 11 groups (five microwave treatment levels, five sham exposure groups, and the additional control group), then placed on portable styrofoam platforms to facilitate movement in and out of the chambers and to permit recording of the precise location of each tagged bee within the chambers. The order in which the microwave treatments and their corresponding sham exposures were conducted each day was dictated by a Latin square (5 by 5) such that each of the five 30-min treatment levels occurred in a different order on each day.

Temperature in the chambers was measured with liquid crystal thermometers (two within each chamber) and recorded before and after each exposure period. A recording hygrothermograph was present in the sham chamber throughout the study. Exposures were completed within ca. 8 h after the time when bees were first removed from their respective colonies.

Microwave radiation utilized for treatments was generated by a 2.45-GHz continuous wave power supply capable of generating up to 300 W of power (ripple <2%). Radiation was transmitted by waveguides from the power supply to a standard gain Narda (model 644) horn antenna mounted in the top of a rectangular exposure chamber. Walls were lined with Eccosorb HT-99 (Emerson and Cuming, Canton, Mass.). The treatment area (61 by 61 cm) was a styrofoam platform (4 cm thick) located 121 cm from the horn and resting on SPY-12 absorber (Emerson and Cuming, Canton, Mass.). Microwave energy entering the chamber was monitored continuously with a Boonton 41-4A power detector. A crystal detector (Hewlett-Packard) was substituted periodically for the Boonton detector to check the wave-form from the power supply. Exposures at 25 and 50 mW/cm^2 were conducted by utilizing the waveguide system and varying the power to the magnetron. Lower power levels were produced with the use of an attenuator.

The sham chamber was constructed identically to the treatment chamber and connected to the treatment chamber as a means of receiving a constant flow of effluent air and sharing any chamber odors or pheromones released by treated bees. This arrangement also equalized ambient air humidity (38 to 66% RH) and temperature (24 to 30° C) in both chambers during the respective treatments.

After all exposures had been completed for the day, bees were released directly into the runway leading to their hive. Beginning the day after release, a census of surviving bees was taken in each colony at least once each day. A Plexiglas® grid placed

against the observation hive glass wall permitted the observer to scan the combs systematically while recording observations on a tape recorder. Observations were continued until 31 August 1979, yielding a total of 50 censuses (28 morning and 22 afternoon).

Results and Discussion

Approximately 50% of the tagged bees present in a colony were observed in any one census. Some bees could not be observed because they were inside cells, on the top, bottom, or sides of comb frames, or simply positioned such that tags were not visible.

Of the 2,750 bees tagged during the study, 80% (2,217) were observed at least once during the posttreatment censuses. Bees not observed may be accounted for in part by rejection after introduction (primarily because of odors introduced in handling and the period of time bees were isolated from colony odors), normal mortality before being observed (ca. 3 to 5% daily is expected), and the loss of some tags (sometimes removed by other bees during grooming). The numbers of tagged bees observed on the first day posttreatment in the five hives were 409, 412, 466, 496, and 434, respectively, with a mean of 443 and a standard deviation of 33 bees. These variations were not significantly different. Surviving bees constituted 80% (999 bees) of the microwave exposure group, 81% (1,012) of the sham group, and 82% (44) of the laboratory control group. The remaining data are shown in Table 1. No significant differences were found between the surviving bees observed in corresponding microwave and sham exposure groups or between any microwave or sham groups, compared with the laboratory control group.

A preliminary analysis of the data indicated that longevity for microwave, sham, and control groups was similar and that less than 20% of the bees treated were still alive 21 days after exposure. Subsequently, data analysis on surviving bees was restricted to censuses taken on days 1, 6, 11, 16 and 21 after exposure (Table 2). No significant differences were found in the longevity of any of the treated, sham, or control groups.

Because of the mobility of bees within the colony, some bees were observed more than once during a single census. The frequency of multiple observations was analyzed (Table 3) to assess the possibility that bees may have become hyperactive, with resulting increased mobility, as a result of microwave treatment. This frequency was predictably greater at the beginning of the experiment because the larger population of tagged bees increased the time required per hive for the census (ca. 30 min per hive on day 1, diminishing to ca. 5 min on day 21), thereby

Table 1.—Number of bees present in glass-walled observation colonies after 30-min exposures to 2.45 GHz of CWM radiation[a]

Treatment (mW/cm^2)	No. of bees/50 bee groups in colony: 1	2	3	4	5	Treatment Total	Mean	SD
3	37	35	43	41	35	191	38.2	3.3
Sham	35	39	44	46	42	206	41.2	3.9
6	37	37	40	44	43	201	40.2	2.9
Sham	38	35	42	45	43	203	40.6	3.6
9	37	37	41	48	35	198	39.6	4.6
Sham	33	37	42	43	44	199	39.8	4.2
25	34	41	43	46	36	200	40.0	4.4
Sham	40	38	42	46	37	203	40.6	3.2
50	41	40	43	47	38	209	41.8	3.1
Sham	28	38	43	45	37	201	40.2	3.2
Control	39	35	43	45	44	206	41.2	3.7

[a] 550 bees were sampled from a different colony on each of 5 consecutive days and divided into 11 treatment groups of 50 bees each.

Table 2.—Longevity of bees within glass-walled observation colonies after 30-min exposures to 2.45 GHz of CWM radiation[a]

Treatment (mW/cm^2)	Days posttreatment 1	6	11	16	21
3	23.4 ± 5.4	15.4 ± 2.4	13.8 ± 2.2	11.0 ± 3.7	9.2 ± 2.6
Sham	22.6 ± 4.3	14.8 ± 3.1	13.0 ± 2.5	10.8 ± 2.8	8.2 ± 3.3
6	21.0 ± 6.1	16.4 ± 4.7	14.6 ± 4.0	10.0 ± 4.1	6.1 ± 2.5
Sham	26.2 ± 5.7	16.4 ± 3.8	12.6 ± 2.0	12.4 ± 3.3	9.2 ± 4.0
9	20.4 ± 3.8	15.4 ± 2.2	14.2 ± 1.9	12.4 ± 2.9	9.4 ± 2.3
Sham	18.2 ± 2.4	14.6 ± 2.2	14.2 ± 4.6	10.2 ± 4.8	8.8 ± 3.3
25	22.2 ± 2.7	15.2 ± 3.6	13.6 ± 4.4	10.4 ± 2.4	7.2 ± 1.3
Sham	20.4 ± 3.7	15.8 ± 2.8	15.6 ± 3.7	9.0 ± 2.6	9.4 ± 3.7
50	23.8 ± 4.5	18.2 ± 3.9	13.8 ± 1.9	9.0 ± 3.3	6.4 ± 1.5
Sham	21.2 ± 6.1	16.4 ± 2.7	15.6 ± 2.4	11.0 ± 1.2	8.0 ± 1.6
Control	20.8 ± 4.4	14.8 ± 3.2	11.4 ± 4.4	10.4 ± 3.7	6.8 ± 2.4

[a] Each value represents mean ± 1SD based on five groups of 50 bees sampled from a different colony on each of 5 consecutive days.

Table 3.—Number of multiple observations during each census of individually tagged bees in glass-walled observation hives after 30-min exposures to 2.45 GHz of CWM radiation[a]

Treatment (mW/cm^2)	Days posttreatment				
	1	6	11	16	21
3	4.8 ± 1.5	2.4 ± 2.0	1.4 ± 1.1	1.8 ± 1.65	0.8 ± 1.8
Sham	5.0 ± 3.0	2.0 ± 1.7	1.8 ± 1.6	0.6 ± 0.9	0.4 ± 0.6
6	2.2 ± 3.4	1.0 ± 1.2	1.0 ± 1.2	1.0 ± 1.0	0.8 ± 1.3
Sham	6.6 ± 2.3	1.2 ± 1.1	1.4 ± 1.7	0.8 ± 0.8	1.8 ± 1.5
9	5.4 ± 2.6	0.8 ± 1.1	1.6 ± 2.2	2.2 ± 1.1	0.8 ± 0.8
Sham	3.0 ± 1.4	0.8 ± 1.3	2.0 ± 1.0	0.4 ± 0.6	0.8 ± 0.8
25	4.4 ± 2.6	1.2 ± 0.5	2.6 ± 1.1	1.2 ± 1.6	1.4 ± 1.1
Sham	6.2 ± 2.4	1.8 ± 1.5	1.8 ± 1.3	0.4 ± 0.9	0.6 ± 1.3
50	5.6 ± 2.6	2.0 ± 1.0	2.0 ± 1.4	1.2 ± 1.1	0.6 ± 0.6
Sham	5.2 ± 2.2	2.2 ± 1.6	2.8 ± 2.3	0.4 ± 0.6	0.4 ± 0.6
Control	5.4 ± 1.8	1.2 ± 1.3	1.0 ± 1.2	1.0 ± 1.0	0.8 ± 0.8

[a]See footnote to Table 2.

increasing the opportunity for multiple recordings of mobile bees during any given census.

Morning and afternoon census data were analyzed for days 1, 6, 11, 16, and 21 for (1) the total number of bees observed, (2) the number of individual bees observed, and (3) the frequency of multiple observations. These data were used for the following orthogonal comparisons: (1) corresponding microwave and sham exposure groups at each of the five treatment levels, (2) corresponding exposure groups for morning and afternoon censuses, (3) the five microwave exposure levels grouped versus the five sham exposure levels, (4) the five sham exposure groups collectively versus the laboratory control group, and (5) the five microwave exposure groups collectively versus the laboratory control groups. No significant differences were found in any of these comparisons ($P = 0.10$).

Our data indicate that 30-min exposure of adult honey bees to 2.45 GHz of CMW at selected power densities between 3 and 50 mW/cm^2 does not significantly affect the survival, longevity, or intracolony mobility of honey bees.

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