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Longevity and Food Consumption of Microwave-Treated (2.45 GHz CW) Honeybees in the Laboratory

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Adult honeybees, confined singly or in small clusters, were exposed for 0.5, 6, and 24 hours to 2.45-GHz continuous wave microwave radiation at power densities of 3, 6, 12, 25, and 50 mW/cm². Following exposure, bees were held in the incubator for 21 days to determine the consumption of sucrose syrup and to observe mortality. No significant differences were found between microwave-treated and sham-treated or control bees.

Key words: microwaves (2.45 GHz CW), honeybees, solar power satellites, longevity, food consumption

INTRODUCTION

A system for obtaining solar energy from outer space has been proposed [Glaser, 1968, 1980]. Large solar power satellites (SPS) would be placed into geosynchronous orbit where they would collect solar energy, transform it to microwaves, and beam them to receiving antennas (rectennas) on earth. Electricity would be produced at the rectennas and transmitted by conventional high voltage lines to population centers. The system has the potential of continuously generating up to 5 gigawatts for each satellite.

One very attractive feature is the expectation of minimal ecological impact. However, the complexities of biological systems demand that a thorough environmental assessment be conducted prior to making major engineering commitments to the system [Koomanoff and Sandahl, 1980]. A potential impact is on airborne biota that either drift passively, or fly over or near, the ca 10-km diameter rectenna where 2.45-GHz continuous-wave microwave power densities may range between ca 1 mW/cm² near the edge and 23 mW/cm² at the center. Furthermore, some scattering of the microwave energy would cause much lower power densities at great distances from the rectennas. The thresholds of perception for inverte-

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brates are unknown, and even if perceived, the behavioral and physiological responses are also unknown.

Honeybees have been chosen as a primary test organism because of their great sensitivity to several kinds of electromagnetic radiation and their ecological significance as pollinators in the production of food in the United States [Gary and Westerdahl, 1978]. Consequently, this study is one of a series designed to detect any biological effects on honeybees caused by microwaves at power densities anticipated in the SPS system. The specific objective of the research reported herein is to determine if prolonged microwave exposure of honeybees induces metabolic, behavioral, or other changes that may affect survival or longevity of confined bees.

MATERIALS AND METHODS

Experimental Design

In this factorial study, bees were exposed at 6 microwave power densities (0, 3, 6, 12, 25, and 50 mW/cm^2) for 3 exposure periods (0.5, 6, and 24 hours). At each power density we exposed 100 bees that were confined in a cylindrical cage that required the bees to form a cluster, and 100 bees that were confined singly in compartments of small cages. Two identical groups of 200 bees were used in the sham chamber and in the laboratory, respectively, as controls during the microwave exposure treatments.

The experiment was conducted in a split-plot design with the six exposure levels randomized as main plots and the three exposure durations randomly assigned to subplots within each main plot. One exposure level-duration combination (including the two control groups, in addition to the microwave treatment group, and the two caging regimes), consisting of 600 bees, was run on each of 18 days, yielding a total of 10,800 bees used in this study.

Exposure System

The exposure system was designed to simulate microwave exposure that would be encountered by airborne biota within and near SPS rectennas. Honeybees in styrofoam cages were arrayed on top of a styrofoam exposure platform (61 × 61 cm) located 121 cm below a standard gain horn (Narda model 644), mounted vertically in the top of a microwave anechoic chamber (88 × 88 × 196 cm). The outer walls of the anechoic chamber were constructed of plywood and lined inside with sheet aluminum. A second interior chamber, separated from the outer wall by a 5-cm vented air space, was constructed of microwave absorbing material (Emerson and Cuming HT-99 ceramic absorber for the walls and ceiling, and SPY-12 pyramidal rubberized absorber for the floor immediately beneath the styrofoam exposure platform).

Power was conveyed from a 2.45-GHz continuous-wave power supply (ripple < 2%) through waveguides into the horn. Power levels within the microwave exposure chamber were monitored continuously by a power detector (Boonton model 41-4A) connected to a 50-dB cross guide coupler (Arra model 284-602-50-n) and to a digital multimeter (Data Precision model 1350). The power detector was calibrated with a microwave meter (Narda model 8611) and probe (Narda model 8623) that had been calibrated against a three-element orthogonal dipole probe

(custom built by Environmental Protection Agency, Research Triangle Park, North Carolina) which was, in turn, calibrated with a reference probe at the U.S. National Bureau of Standards.

The sham chamber was constructed identically to the treatment chamber and connected to it through an insulated metal duct. It received a constant flow of effluent air so that bees in the sham chamber would be exposed to any chamber odors or pheromones released by the treated bees. This arrangement also equalized humidity and temperatures in both chambers during the treatments.

During exposure, four gallium-arsenide fiberoptic probes (designed and constructed by D. Christensen, University of Utah) were used to measure 1) ambient temperature within the microwave treatment chamber, 2) temperature within a cluster of bees in a cylindrical cage, 3) the internal thoracic temperature of an individual bee constrained by nylon strands to a styrofoam block, and 4) ambient air temperature within the sham treatment chamber. Outputs from these probes were recorded continuously on chart recorders (Omniscribe model B5237-5). Additionally, two copper-constantan thermocouples (Omega models SCPSS-020-6 and HYP-1) in the sham chamber monitored 1) temperatures within a cluster of bees in a cylindrical cage, and 2) the internal thoracic temperature of an individual bee, constrained as in the treatment chamber. The thermocouples were connected to electronic ice-point references (Omega model MCJ-T), and recordings were made on a chart recorder (Omniscribe model B5237-5). Humidity within the sham chamber was recorded with a hygrothermograph (Bendix model 594).

Preparation of Materials

Each morning, approximately 2,000 bees were removed from the same brood comb frame from each of three colonies and placed in a common cage. They were fed 50% sucrose solution, then released in a small darkened room on a platform abutting a vertical glass window, with natural back-lighting as the sole source of illumination. Bees attracted to the glass surface were captured individually and placed into one of two types of exposure cages (Fig. 1). The cylindrical cage was designed to hold 100 bees in a cluster of a size that theoretically should have maximized energy absorption for the wavelength (12.5 cm) that was used. This cage was made of fiberglass window screen (10 cm long) wrapped around two styrofoam disks (4 cm in diameter and 1.5 cm thick) and secured with rubber bands, thus containing the bees in a cluster ca 5 cm long and 4 cm in diameter. Bees were supplied with food during confinement by placing disks of invert sugar fondant (1 cm diameter and 0.5 cm thick) on each end, and adjacent to the styrofoam disks.

The second exposure cage was a rectangular styrofoam block (13 × 2.5 × 1 cm) that held five bees individually in circular holes (2 cm diameter and 0.7 cm deep) (Fig. 1). The holes were covered with fiberglass screen secured with rubber bands. An invert sugar fondant was accessible to the bees through a hole (0.5 cm diameter) in the compartment floor. Each day, 60 cages were prepared, randomized, and divided equally between the microwave, sham, and laboratory control treatments.

Microwave and sham groups were placed in identical anechoic chambers, and the laboratory control group was held in the dark at room temperature (25 °C) and humidity (50% RH) throughout the exposure. Cylindrical cages were placed on their side in the center of each anechoic chamber exposure platform.

Five compartment cages were placed side by side (1 cm between the long axes of the cages) on separate, portable styrofoam platforms (18 × 12 × 2.5 cm), two of which were placed on either side of the cylindrical cage.

Postexposure Procedures

Bees from each treatment group were divided into groups of 20 and transferred to cylindrical wire mesh cages (Fig. 2) (15 cm long and 2 cm diameter). Ten cages were grouped together and held vertically on corks affixed to a platform (35 × 10 × 2 cm) with 5 cm between cages. A paper cylinder (21 × 4 cm) was placed around each cage to provide further separation, and also to prevent intercage fecal contamination. Food (50% solution of sucrose in water) was provided from 3-ml plastic syringes (containing an opening 0.3 cm in diameter made by removing the tips), inserted through a piece of plastic tape that covered the top of each cage (Fig. 2). The cages were held in an incubator (3 × 2 × 2.5 m) at 32 ± 1°C and 50% RH. At three-day intervals following exposure, 1) dead bees in the cage were removed and recorded, 2) the volume of sugar syrup consumed was recorded, and 3) new syringes with fresh syrup were provided (to reduce the possibility of fermentation). Observations were discontinued 21 days after exposure.

RESULTS AND DISCUSSION

Temperature ranges during 6-hour exposures (Table 1) were 1) microwave chamber, ambient (23–30 °C), bee cluster (27–36 °C), single bee thoracic probe

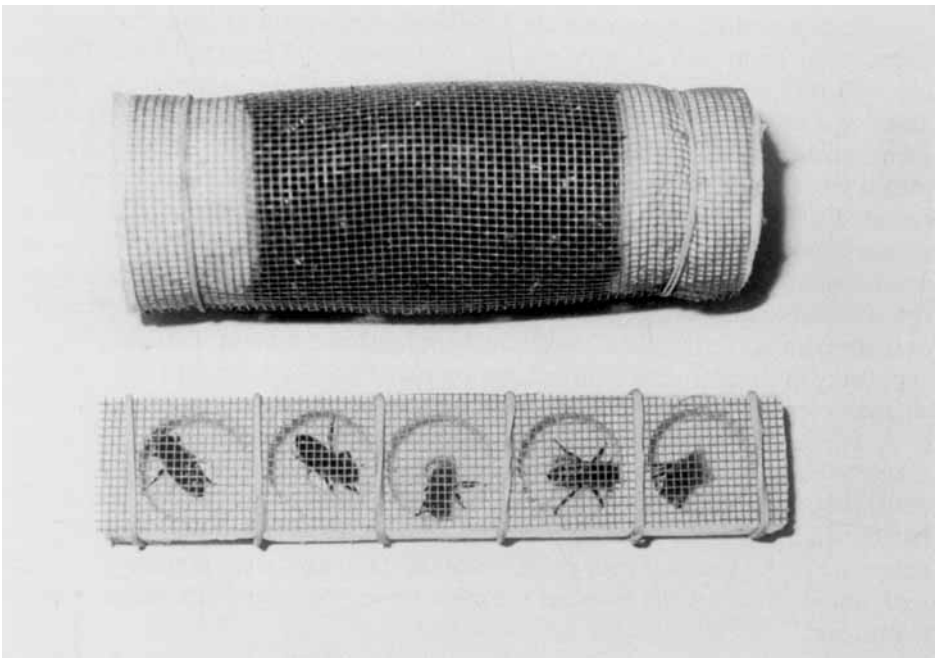

Fig. 1. Microwave transparent cages for confining honeybees during microwave treatments. Cages were made of styrofoam and Fiberglas screen secured with rubber bands. The cylindrical cage (top) (4 cm diameter, 10 cm long) caused clustering of bees in the reduced space. The 5-compartment cage (13 × 2.5 × 1 cm) separates bees into holes (2 cm diameter, 0.7 cm deep) for individual bee exposures.

TABLE 1. Temperature Ranges During 6-Hour Exposures Within Sham and Microwave Chambers, Bee Clusters, and Individual Bee Thoraxes *

Power density mW/cm²	Exposure chamber	Temperature °C: Ambient in chamber Min	Ambient in chamber Max	Bee thorax (internal) Min	Bee thorax (internal) Max	Bee cluster (internal) Min	Bee cluster (internal) Max
0	Sham	24	26	25	30	28	39
	Microwave	24	25	22	27	28	36
3	Sham	24	26	23	29	28	35
	Microwave	23	24	25	36	27	36
6	Sham	25	27	29	30	30	37
	Microwave	25	26	26	32	27	35
12	Sham	24	26	26	28	25	37
	Microwave	25	26	24	26	27	35
25	Sham	25	28	25	28	27	35
	Microwave	26	27	25	28	28	36
50	Sham	28	29	28	35	31	39
	Microwave	27	30	27	36	30	36

* Mortality for the individual bees with internal thoracic probes was high for the 24-hour treatments. Consequently, all data in this table are from the 6-hour exposure treatments. Each range is based on a single sample.

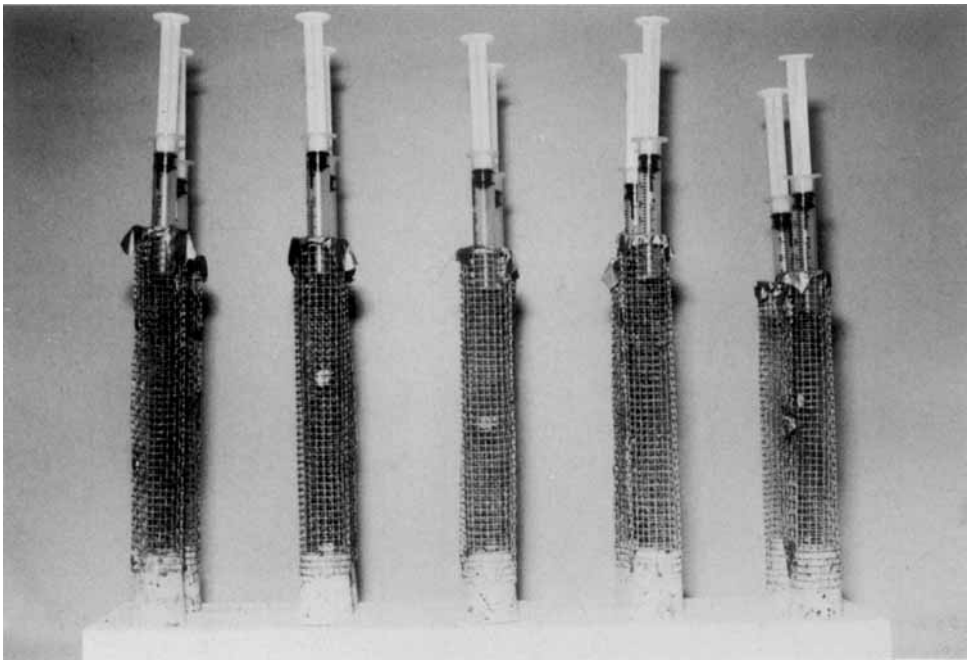

Fig. 2. Posttreatment, 8-mesh wire cages (2 cm diameter, 15 cm long) are mounted on corks affixed to a wooden platform. Each cage holds 20 bees that have access to food (50% solution of sucrose in water) in the 3-ml plastic syringes (held in position by insertion through plastic tape) with 0.3-cm diameter openings made by removing the tips. Cages are isolated from each other by paper cylinders (21 × 4 cm) (not shown) to prevent intercage fecal contamination.

(22–36 °C); and 2) sham chamber, ambient (24–29 °C), bee cluster (25–39 °C), single bee thoracic probe (23–35 °C). Relative humidity within the sham chamber (effluent air from the microwave chamber) was 50–60%. Mortality during treatment was low (Day 0, Figs. 3–8) and did not differ significantly between treatments and controls.

The average specific absorption rates for an isolated bee for E, K, and H polarizations are 0.50, 0.030, and 0.025 W/kg, respectively, for an incident power density of 1 mW/cm². These estimates (made by Carl Durney, University of Utah) are based on a spheroidal model of a lossy dielectric and a long wavelength approximation [Johnson et al, 1975]. The average specific absorption rates in the center of the cluster of bees for E and H polarizations are 0.40 and 0.34 W/kg, respectively, for an incident power density of 1 mW/cm². These estimates (made by H. Massoudi, Unversity of Utah) are based on a prolate spheroidal model consisting of two-thirds muscle tissue [Durney et al, 1978].

There were no significant differences in rate of food consumption for any of the groups, thereby indicating that behavior and metabolic functions were normal after microwave exposure. The mean consumption per surviving bee per day was ca 30 (± 5) μl of the 50% sucrose syrup (or 0.06 Kcal).

Daily mortality of bees, for all durations of exposures, was essentially identical. Consequently, only the data for 24-h exposures are presented in Figures 3–8. There are no indications in the survival data that microwaves at the power densities tested have detectable effects on confined honeybees. The survival curves for all groups are similar. Orthogonal comparisons [Sokal and Rolf, 1969] indicated no significant differences (0.10 level) between microwave, sham, and laboratory

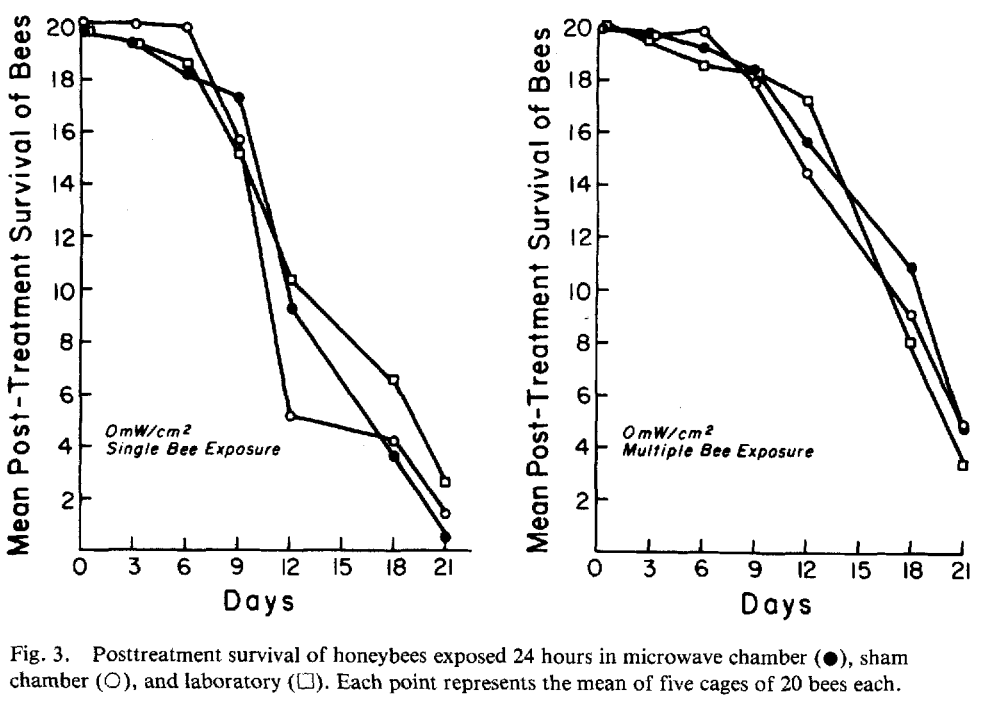

Fig. 3. Posttreatment survival of honeybees exposed 24 hours in microwave chamber (●), sham chamber (○), and laboratory (□). Each point represents the mean of five cages of 20 bees each.

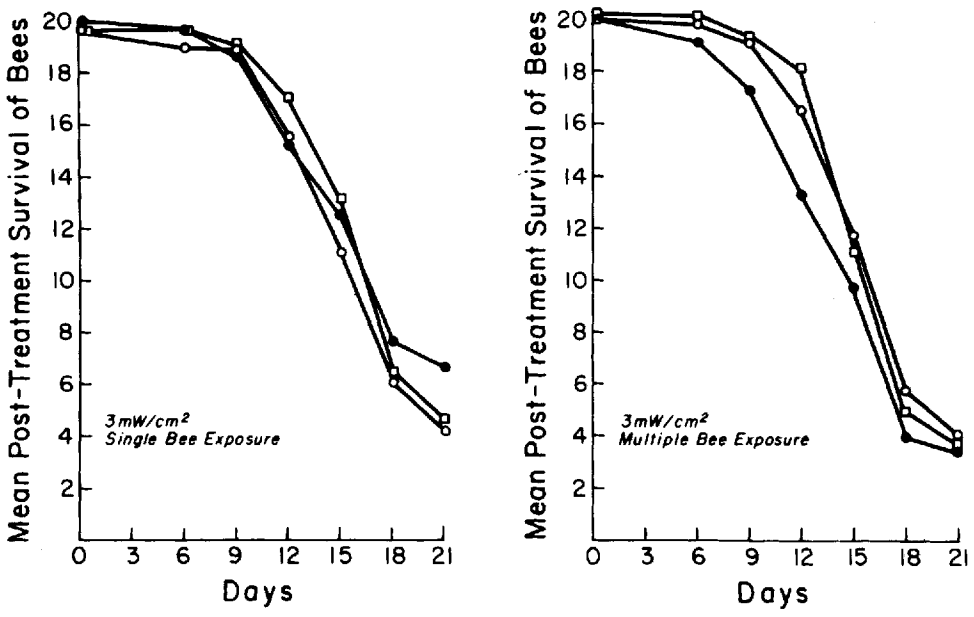

Fig. 4. Posttreatment survival of honeybees exposed 24 hours in microwave chamber (●), sham chamber (○), and laboratory (□). Each point represents the mean of five cages of 20 bees each.

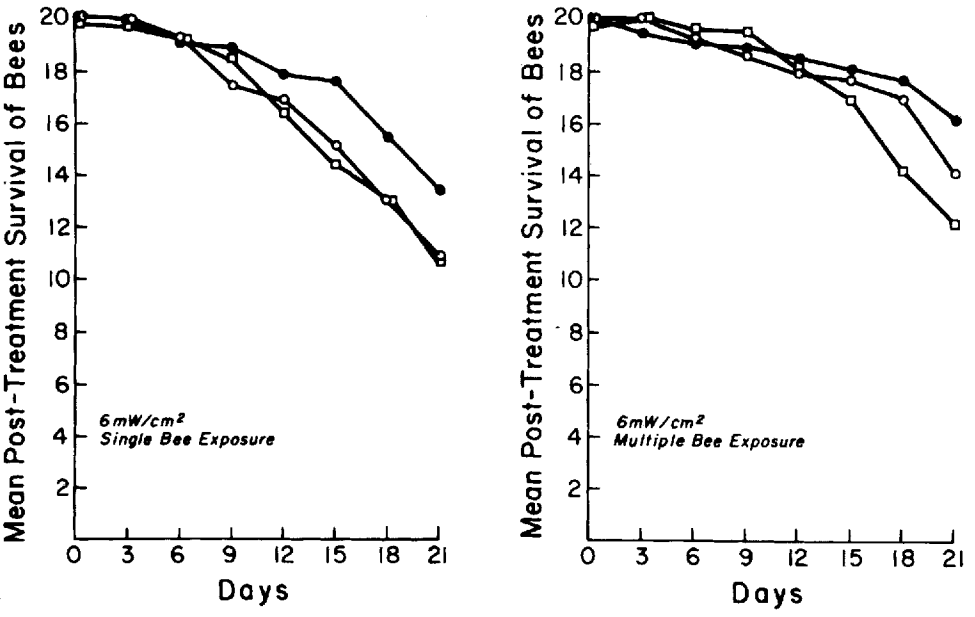

Fig. 5. Posttreatment survival of honeybees exposed 24 hours in microwave chamber (●), sham chamber (○), and laboratory (□). Each point represents the mean of five cages of 20 bees each.

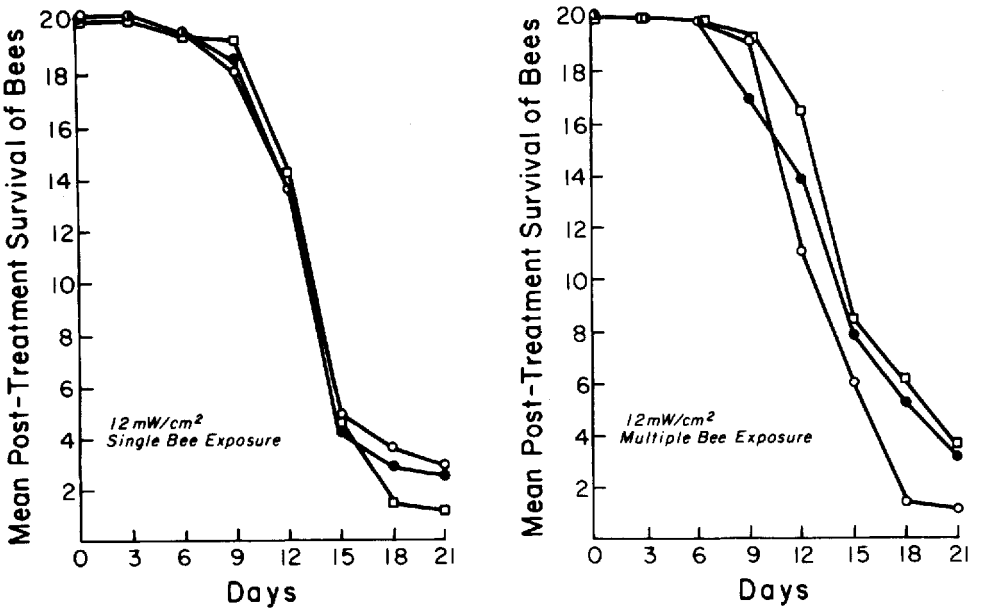

Fig. 6. Posttreatment survival of honeybees exposed 24 hours in microwave chamber (●), sham chamber (○), and laboratory (□). Each point represents the mean of five cages of 20 bees each.

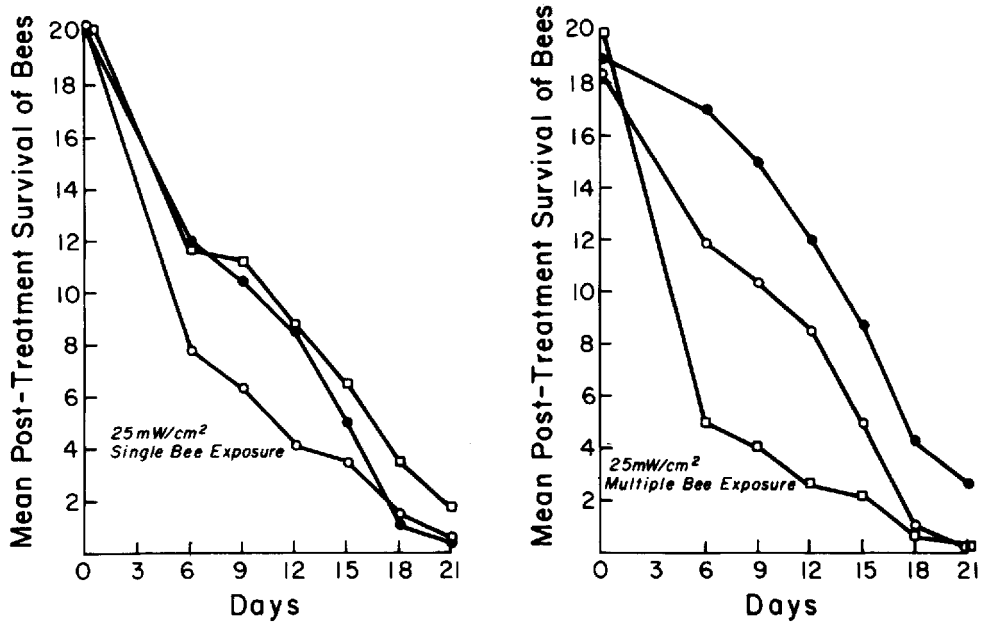

Fig. 7. Posttreatment survival of honeybees exposed 24 hours in microwave chamber (●), sham chamber (○), and laboratory (□). Each point represents the mean of five cages of 20 bees each.

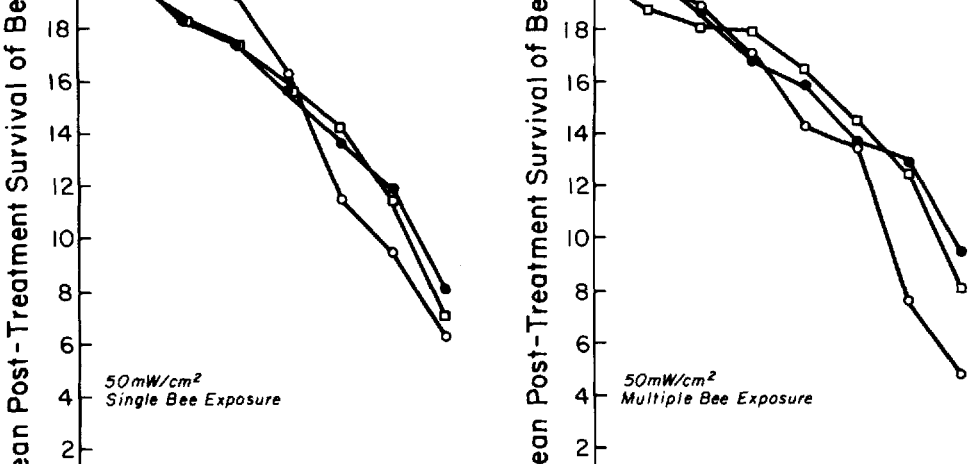

Fig. 8. Posttreatment survival of honeybees exposed 24 hours in microwave chamber (●), sham chamber (○), and laboratory (□). Each point represents the mean of five cages of 20 bees each.

control groups at any power density on any particular day following exposures. The most probable cause of the higher survival in Figure 5 is that there probably was a higher percentage of young bees in that population at the outset. This could have happened by chance if there was a brood emergence on one or two of the combs that were removed each day for sampling bees from the three colonies. Even so, the relative survival was the same for all treatments and controls.

Apparently, the clustering of bees either did not enhance the absorption of energy to the extent that any effects were noted, or bees were able to dissipate absorbed heat, compared to the single bee exposures, at least with a 24-hour exposure.

CONCLUSIONS

We find no evidence that longevity or food consumption of honeybees, held singly or in clusters, is affected by exposures (up to 24 hours) to 2.45-GHz continuous wave microwaves at selected power densities ranging from 1 to 50 mW/cm^2, which exceeds the level that is anticipated on earth for the SPS system.

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