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Continuous Exposure of Chicks and Rats to Electromagnetic Fields

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#2798

Abstract—Growth rate and feed consumption depressions were observed in groups of 25 day-old male chicks when exposed in metal cage environments to the following CW fields: 1) a UHF wave at 880 MHz in a very low-Q cavity resonator energized by a 220-mW power source (values of electric field square E^2 divided by the intrinsic impedance of free space $\eta = 377\ \Omega$ were measured resulting in a maximum value of 550 μW/cm² with a "hot spot" of 900 μW/cm²); 2) a VHF wave at 260 MHz in a very low-Q cavity resonator, energized by a 220-mW power source (values of E^2/η were not measured, but the values should have been similar to those measured in the UHF facility); 3) an extremely low frequency (ELF) electric field at either 45 or 60 Hz with calculated electric field strength of 3500 V/m; 4) an ELF magnetic field at either 45 or 60 Hz with 1.3 G was measured.

Adrenal glands of chicks exposed to the 880-MHz wave were compared with those from control chicks. Smaller adrenals were observed in the treated group of birds.

Growth depression was also observed in rats exposed to the UHF field at 880 MHz. Mean adrenal weights of the treated and control rats did not differ significantly; however, spleen and thymus weights of the treated rats were notably larger.

Potential causes of the growth responses observed are discussed.

I. INTRODUCTION

A SIGNIFICANT amount of research has been reported on the biological effects of direct tissue heating from exposure to electromagnetic radiation, and excellently reviewed by Michaelson [1].

Biological effects at power levels below 10 mW/cm² have been observed with CW and pulsed signals and briefly discussed by Frey [2]. Guy *et al.* [3] exposed the cat to microwave radiation at 918 MHz with power levels below 2.6 mW/cm² and induced an increase in brain temperature with maximum changes occurring in the thalamus region, and with subsequent effects on somatosensory receptors in the cat's paw. Later Guy *et al.* [4] reported that an auditory sensation may be elicited in cats and humans by pulse energies larger than 20 μJ/cm², regardless of peak power.

Further investigation of the effects of low-level CW and pulsed electromagnetic radiation on animal physiology is necessary. The object of this study is to report physiological responses observed in baby chicks and rats when continuously exposed to CW electromagnetic radiation in a very low-Q cavity resonator with field levels below, or comparable to, previously reported values causing biological effects. Exposure effects on chicks to electric and magnetic fields at 45 and 60 Hz are also reported.

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II. EXPERIMENTAL

A. Treatment Groups

A total of six consecutive experiments were conducted. All experiments used chicks with the exception of experiment 3. In experiment 3 rats were exposed to an electromagnetic field at a frequency of 880 MHz. In experiments 1, 2, and 4, chicks were exposed only to an electromagnetic field at a frequency of 880 MHz, while in experiments 5 and 6, three additional electromagnetic fields were added.

In experiments 1 and 2, a total of 50 incrossbred day-old male chicks were randomly divided into 2 groups. Each group was placed in metal chick brooding cages 0.91 × 0.61 × 0.30 m with feeders and waterers attached to the outside of the cages. A similar procedure was followed in experiment 4; however, the experiment had to be discontinued because of severe sexing errors and disease exposure that differentially affected the experiment.

In experiments 5 and 6, a total of 125 incrossbred day-old male chicks were randomly divided into 5 groups of 25 chicks each and treated as follows.

1) Group 1—control.

2) Group 2—UHF wave at 880 MHz in a very low-Q cavity resonator, energized by a 220-mW power source.

3) Group 3—VHF wave at 260 MHz in a very low-Q cavity resonator, energized by a 220-mW power source.

4) Group 4—Extremely low frequency (ELF) electric field: 3500 V/m at 60 Hz in experiment 5 and 45 Hz in experiment 6.

5) Group 5—ELF magnetic field: 1.3 G at 60 Hz in experiment 5 and 45 Hz in experiment 6.

The treatments were applied to the chicks continuously for periods up to 28 days of age. Differences in body weight, feed consumption, livability, and behavior were used to compare treated with control groups. Body weight can be a convenient and sensitive parameter for measuring treatment effects over long periods of time.

Contemporary domesticated birds often live in metal cage environments. To be certain that the chicks would grow in a normal environment, metal brooding cages were used. The electronic system was built around these cages. As a result, only the effects of electromagnetic radiation inside a very low-Q cavity resonator could be considered.

The walls of a chick brooding cage are not flat metal walls similar to those one experiences when analyzing electric and magnetic field configurations. As a result, the accuracy of electrical measurements is reduced, and errors in excess of 100 percent in some of the electrical quantities would be considered acceptable. Some inaccuracy in the determination of electrical quantities in this case was traded for realistic animal environmental conditions and improved sensitivity to better assess treatment effects. Each treatment used a different facility described elsewhere [5]-[11], but is reproduced here for convenience.

Room temperature and humidity were not completely controlled. Periodic measurements of temperature inside the various cages failed to disclose temperature differences of significance.

A homogeneity trial was designed at the end of experiment 6 to determine if the biological responses noted were the result of exposure to the various experimental fields. Twenty-five day-old male chicks were placed in each of the five exposure facilities and treated similarly. All electric equipment was energized but not electrically connected to the exposure facilities. The birds were kept in the facilities for 28 days.

The laboratory rats were continuously exposed from birth to 47 days of age to a CW–UHF wave at a frequency of 880 MHz [5]. Four metal cages 0.24 × 0.18 × 0.18 m in size were used, and each contained a pregnant laboratory rat. Subsequent progeny were designated groups 1, 2, 3, and 4. Four other pregnant laboratory rats and subsequent progeny were kept in similar individual metal cages, shielded from electromagnetic waves and used as controls. These were called groups 5, 6, 7, and 8. Body weight was recorded periodically until the rats were 47 days old. Because the young were not born on the same day, comparison of body weights was possible only after correction for age. An average growth curve for treated and control rats was obtained to effect the weight–age correction.

B. UHF Electromagnetic Field

The exposure facility used to radiate chicks with fields at 880 MHz consisted of a horn antenna positioned on the metal brooding cage. A coaxial-to-waveguide converter was connected to the horn antenna. The signal from the source was attenuated and then applied to the converter. This is shown schematically in Fig. 1. Measurements of the electric field inside the metal brooding cage were made using an electromagnetic leakage monitor surveyor, Narda 8100, with an applied UHF signal having an available input power of 220 mW at 915 MHz.

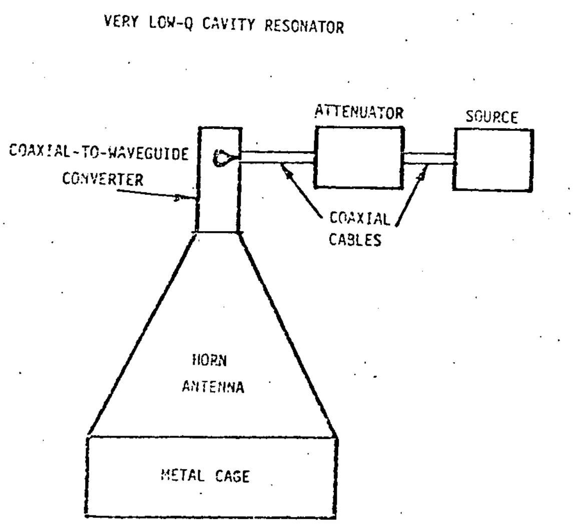

Fig. 1. Diagram showing the components of the exposure facility used to radiate chicks in the UHF electromagnetic field.

Survey of the field inside the unloaded exposure facility (without chicks) indicated a predominance of the TE_{10} mode. The calculated input power density at the center of the cage when only a TE_{10} mode is present should be twice the average input power density; that is, 66 μW/cm². For 100-percent reflection from the metallic floor of the cage, the electric field at a maximum position of the standing wave should be twice that of the incoming wave. Since the meter used measures the square of electric field E^2 divided by the intrinsic impedance of free space η = 377 Ω, its reading at this position should be four times that of the incoming wave, or 264 μW/cm². Measurements with an unloaded system (no chicks), and with the probe of the meter introduced through the top, front, or side of the metal cage, yielded a value of approximately 550 μW/cm², only twice that anticipated by calculation. This difference could be attributed to either a lack of precision in measurement, or to some very low-Q resonance in the system.

Measurements of E^2/η with concentrated and spread loading (using 1–25 day-old chicks) were also obtained. E^2/η decreased in proportion to loading. With maximum spread loading, (all 25 day-old chicks inside the cage), for example, the maximum E^2/η at the center of the cage was approximately 250 μW/cm². Waterer and feeder location and shape also have an influence in the field distribution inside the cage, and could be responsible for a "hot spot" observed in the center of the cage at a height of 9.5 cm from the floor. The value of E^2/η at this point was found to be 900 μW/cm².

Measurements of VSWR were made to calculate the power absorbed by the chicks at various ages and at various positions inside the cage. Power absorbed by 25 chicks (not older than 14 days) when concentrated at the center of the cage was 5–10 times larger than the power absorbed by the chicks when concentrated at one corner of the cage. This difference was decreased to a factor less than 3 when the 25 chicks were 22 days or older. This decrease was primarily the result of the older chicks occupying more space in the cage, hence preventing concentration at the center or corners of the cage.

Measurements also were attempted with a single chick located at the center and at one side of the cage. This was possible only with the chick located at the center of the cage and with chicks more than 14 days old because the magnitude of power to be measured was below the sensitivity of the measuring system. These powers were 9, 14, and 18 mW for a 14, 22, and 29 day-old chick, respectively. The error associated with these measurements is high, possibly in excess of 100 percent. Assuming that the available power at the center of the empty cage is given by E^2/η = 500 μW/cm², the equivalent cross-sectional area of the chick at these three ages are 18, 28, and 36 cm², respectively. These values may vary by as much as a factor of 4.

C. VHF Electromagnetic Field

An adapter from a coaxial line (50 Ω) to a rectangular waveguide (0.736 by 0.368 m) was built. A horn was constructed at the end of the adapter with appropriate dimensions so that the adapter and horn would sit on the metal chick brooding cage. The adapter was connected to a VHF signal source consisting of a unit oscillator (General Radio type 1215-C) capable of delivering 200 mW of VHF power to a 50-Ω load. The exposure facility was similar to that shown in Fig. 1. The power loss from reflections and from dissipation on the metal walls of the waveguide and horn were obtained from VSWR measurements with the horn in open space, and with the horn sitting on top of a metal surface. The lowest frequency of VHF signal with reasonable power loss was 260 MHz ($P_{out}/P_{in} = 0.84$), and was the selected operational frequency.

Because of the dimensions of the cage (0.91 × 0.61 m), only the TE_{10} mode was expected to be excited inside the cage at the frequency used. Thus an analysis similar to that used to estimate the maximum value of E^2/η for the UHF exposure facility was used. If standing waves result only from reflections caused by the metallic floor of the cage, the value of E^2/η measured by a power density meter should have a maximum value of 264 μW/cm².

D. ELF Magnetic Field

To expose chicks to an ELF magnetic field, a coil with 22 turns of insulated copper wire (AWG number 14) was wound around a metal chick brooding cage. The power dissipated by the coil was equal to 8 W with an electric current of 4 A flowing through the coil. A Hall probe was used to measure the magnetic field at various positions inside the cage. An average magnetic field of 1.25 G ± 10 percent was measured.

E. ELF Electric Field

An ELF electric field was produced by replacing the top of a metal brooding cage with an electrically insulated aluminum plate with dimensions 0.4 × 0.7 m. An audio oscillator in conjunction with a step-up transformer was used to apply a voltage of approximately 800 V between the aluminum plate and the metal brooding cage. The calculated electric field at the center of the cage was 3500 V/m. The cage design was not the best for an accurate calculation of the electric field to which the chicks were exposed, primarily because of the nonuniformity of the field, especially when the chicks were inside the cage. Variations of up to 100 percent in the electric field could exist. The primary concern in these initial electric field experiments was to determine if a physiological response could be produced from exposure. Despite deficiencies in design, the data obtained on growth and feed consumption should be valid, particularly since all other environmental conditions were controlled and kept similar to those of the nonexposed control group.

III. RESULTS

A. Chick Experiments

In experiment 1, 25 chicks were exposed to the UHF field at 880 MHz with a power of 143 mW. At the end of seven days of continuous exposure to this electromagnetic field, the treated chicks averaged 74.4 g in body weight and consumed 72.6 g of feed per bird, while the control group averaged 81.2 g and consumed 88.2 g of feed per bird (Table I). The mean differences are statistically significant.

After 14 days of continuous exposure to the CW–UHF field, the treated males weighed 138.3 g while the controls averaged 152.6 g. Comparable feed consumption data were 104.0 and 146.8 g per bird for the exposed and control groups, respectively. The radiated and control groups at this age differed by 11 percent in body weight and 42 percent in feed consumption.

At the termination of the experiment (23 days), the treated chicks had an average body weight of 217.0 g and the controls 245.0 g. At this point, the comb, adrenal glands, and testes of ten birds from each group were removed and weighed. No statistically significant differences between the two groups were observed for comb and testicle weight; however, an obviously smaller decapsulated adrenal gland was observed in the treated group (18.03 mg) than in the control group (23.22 mg). Statistical analysis of absolute weights yielded an F ratio of 4.06 ($P \leq 0.07$), and analyzing adrenal gland weight per unit body weight an F ratio of 3.60 ($P \leq 0.09$).

In experiment 2, chicks were exposed to the UHF field at 880 MHz, and with an initial power of 180 mW. At the end of the first week, the UHF field was discontinued. On the fourteenth day, a UHF field with a power of only 90 mW was applied to the previously exposed group of chicks. Body weight and feed consumption data were collected on each group through 21 days of age.

The average weights of the treated and control day-old chicks at the beginning of the experiment were 36.2 and 35.6 g, respectively (Table II). After seven days exposure the average body weight of the treated birds was 68.0 g and the controls weighed 78.1 g. The mean difference of 11.1 g is highly significant statistically ($P \leq 0.01$) and agrees in sign with the difference noted in experiment 1.

The power was then turned off for seven days. The average weights for the treated and control birds reversed themselves during this period. The means were 161.0 and 134.2 g per bird, a mean difference of 26.8 g. The surprisingly rapid and statistically significant ($P \leq 0.01$) increase in weight and feed consumption of the treated birds is noteworthy. For convenience, the growth curves for the treated and control chicks are shown in Fig. 2. At 21 days, the weight difference had narrowed to 15.5 g, indicating a depressing effect from the UHF signal.

At this point, the chick facilities were expanded to include VHF electromagnetic, ELF electric, and ELF magnetic fields.

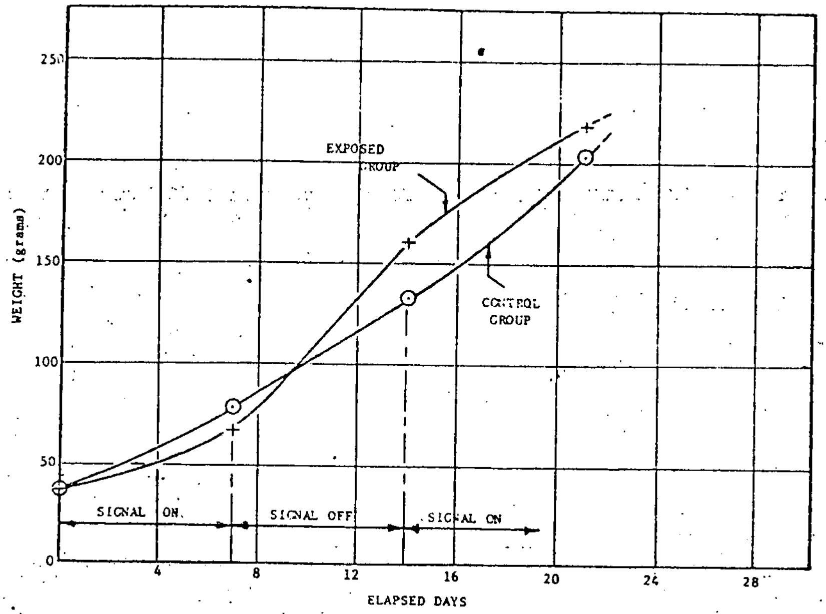

Fig. 2. Effect on growth of baby chicks when intermittently exposed to a UHF electromagnetic field. (Frequency: 880 MHz; power: 180 mW during first seven days and 90 mW during remainder of experiment.)

TABLE I

THE EFFECT OF CONTINUOUS ELECTROMAGNETIC EXPOSURE (UHF) ON GROWTH RATE AND FEED CONSUMPTION OF BABY CHICKS (880 MHz, 143 mW)—EXPERIMENT 1

Age of Birds (Days)	Treated			Controls			F Ratio (Body Wt.)
	No.	Mean Weight (g)	Feed/Bird (g)	No.	Mean Weight (g)	Feed/Bird (g)	
1	75	36.0	--	25	36.0	--	--
7	25	74.4	72.6	25	81.2	88.2	--
14	25	138.3	104.0	25	152.6	146.8	--
23	25	217.0	--	25	245.0	--	5.1[1]

[1] $P \leq 0.03$.

TABLE II

THE EFFECT OF INTERMITTENT ELECTROMAGNETIC EXPOSURE (UHF) ON GROWTH RATE AND FEED CONSUMPTION OF BABY CHICKS—EXPERIMENT 2

Age of Birds (Days)	Treated			Controls			F Ratio (Body Wt.)
	No.	Mean Weight (g)	Feed/Bird (g)	No.	Mean Weight (g)	Feed/Bird (g)	
1	25	36.2	--	25	35.6	--	--
7	24	68.0	69.4	25	78.1	75.3	52.4[1]
14	24	161.0	186.0	25	134.2	146.0	86.3[1]
21	24	218.9	207.0	25	203.4	192.0	7.0[1]

Note: 180 mW of UHF was on from days 1 to 7, UHF was off from days 8 to 14, and 90 mW of UHF was on from days 15 to 21.
[1] $P \leq 0.01$.

TABLE III

THE EFFECT OF FOUR TYPES OF ELECTROMAGNETIC RADIATION ON CHICK GROWTH TO 28 DAYS OF AGE—EXPERIMENT 5

Treatments	No. Birds	Body Weight Means (g)				Feed Efficiency[2]	Livability (%)
		1 Day	9 Days	21 Days	28 Days		
Nonirradiated Control	25	35.8a[1]	65.5a[1]	140a[1]	211a[1]	2.37	100
Continuous 260 MHz	25	35.0a	65.3a	133abc	196a	2.36	100
Continuous 880 MHz	25	35.6a	62.7a	122 c	172 b	2.33	100
60 Hz Electric Field	25	34.2a	65.5a	136ab	201a	2.16	96
60 Hz Magnetic Field	25	35.6a	67.0a	128 bc	189ab	2.29	100

[1] Means having the same letter are not significantly different ($P \leq 0.05$).
[2] Grams of feed consumed per gram of body weight.

TABLE IV

THE EFFECT OF FOUR TYPES OF CONTINUOUS ELECTROMAGNETIC RADIATION ON CHICK GROWTH TO 22 DAYS OF AGE—EXPERIMENT 6

Treatments	No. Birds	Body Weight Means (g)				Feed Efficiency[2]	Livability (%)
		1 Day	9 Days	15 Days	22 Days		
Nonirradiated Control	25	32.4	91.5a[1]	155a[1]	220a[1]	1.93	96
Continuous 260 MHz	25	32.2	91.1a	153a	210ab	1.97	96
Continuous 880 MHz	25	32.4	92.3a	154a	213ab	1.94	96
45 Hz Electric Field	25	32.2	86.0 b	143 b	209ab	2.05	96
45 Hz Magnetic Field	25	32.0	88.4ab	145 b	201 b	2.07	100

[1] Means having the same letter are not significantly different ($P \leq 0.05$).
[2] Grams of feed consumed per gram of body weight.

(260 MHz) reduced growth about 5 percent compared with comparable controls to approximately 21 days of age. The effect on growth was not detectable until the birds were approximately 21 days of age (Tables III and IV). When evaluated statistically, the 5-percent difference in growth was not significant, but consistent in direction for the two experiments.

When similar chicks were exposed to a UHF electromagnetic field (880 MHz), growth depression was severe in experiment 5 (Table III). The chicks in experiment 5 were grown on a low-protein-low-energy diet. The birds in experiment 6 (Table IV) which grew much better, received a high-protein–high-energy diet. It would appear that the superior diet used in experiment 6 may have offered the birds some protection from the effects of the UHF electromagnetic field. No deliberate comparison has all previous experiments has been depressed for the birds exposed to the UHF electromagnetic field.

Feed conversion, defined as the grams of feed required to produce a gram of body tissue (gain), was not significantly influenced by either the VHF or UHF electromagnetic fields (Tables III and IV). The differences in feed efficiency between the controls and the VHF and UHF treatment groups can be explained on the basis of random fluctuations and differential feed wastage. The much improved performance of all groups in experiment 6 is primarily the result of an improved diet fed the birds. In addition, the ambient temperature during experiment

experiment 6. The growth curves for the UHF and VHF groups for experiments 5 and 6 are presented in Fig. 3.

Exposure of chicks to the ELF magnetic field consistently depressed growth rate compared with nonexposed controls by 9–11 percent (Tables III and IV). The depression in growth became obvious after the chicks were nine days old. Birds exposed to the ELF electric field were approximately 5 percent smaller in body weight than the controls (Fig. 4).

Feed efficiency patterns appeared to be different for the 60- and 45-Hz frequencies for both the magnetic and electric field treatment groups. Feed conversion was consistently poorer at 45 Hz, despite the fact that the birds in experiment 6 were on a superior diet. This type of interaction was not apparent when comparable birds were exposed to the VHF and UHF electromagnetic fields. Whether this interaction is real, or occurred by chance, must be determined by additional tests. No significant differences in livability and behavior patterns were noted in either of the two experiments.

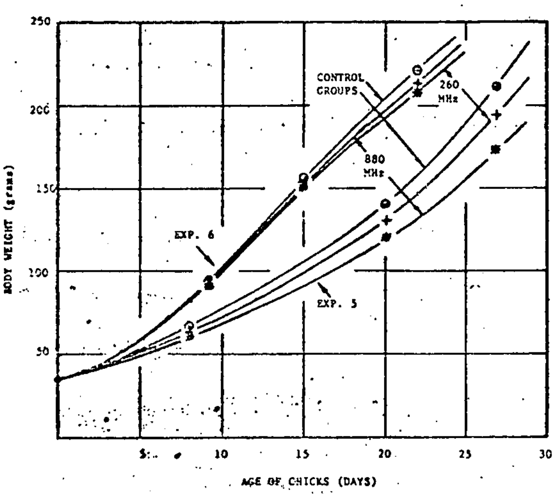

Fig. 3. Effect on growth of baby chicks exposed to continuous UHF (frequency: 880 MHz; power: 220 mW) and VHF (frequency: 260 MHz; power: 220 mW) electromagnetic fields.

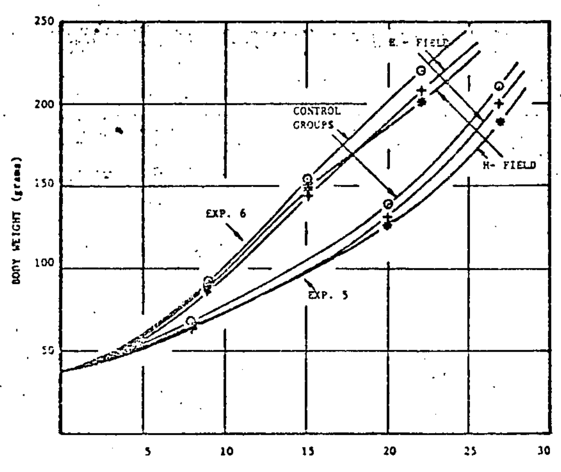

Fig. 4. Effect on growth of baby chicks exposed to continuous electric (electric field intensity: 3500 V/m) and magnetic fields (magnetic flux density: 1.3 G; experiment 5: 60 Hz; experiment 6: 45 Hz).

B. *Homogeneity of Facilities*

An experiment was designed at the conclusion of experiment 6 to evaluate the importance of cage and location differences. None of the 25 chicks in each of the 5 cages received direct electromagnetic exposure as in previous experiments. Mean body weight at 15 days of age for the 5 groups ranged from 109.4 to 116.8 g with a within treatment standard deviation of 15.4 g. Analysis of variance yielded a nonsignificant F ratio of 0.74, indicating similarity between the treatment and error variances. The average weight of the controls was 113.4 g.

At 22 days of age the range in body weight for the 5 cage groups varied from 161.0 to 167.9 g with a within treatment standard deviation of 25.3 g and an F ratio of 0.28, indicating nonsignificant differences among the 5 cage means. At 22 weeks of age the control caged birds weighed 166.8 g. It is concluded that birds in the five nonenergized cage units respond alike when treated alike.

C. *Rat Experiment*

In experiment 3 rats were exposed to the UHF field at 880 MHz with a power of 100 mW from birth to 43 days of age. Mathematical expression for the average individual weight w in grams, for the treated rats as a function of time t in days, was calculated to adjust body weights to a constant age using least square methods, based on 43 data points. The equation obtained was

$$w = 6.79729 - 0.1436372t + 0.1011503t^2 - 0.000808698t^3.$$

For control rats, this expression was calculated based on 48 data points and was

$$w = 11.24318 - 0.6578141t + 0.1347367t^2 - 0.001005204t^3.$$

The adjusted body weights (Table V) were then subjected to analysis of variance. Statistically significant differences in growth rate resulted from exposure to the UHF field (Table V). As the rats increased in age the mean differ-

TABLE V
EFFECT OF CONTINUOUS ELECTROMAGNETIC EXPOSURE ON GROWTH RATE OF BABY RATS—EXPERIMENT 3

Age (Days)	Control Rats: No. of Rats	Control Rats: Mean Weight (g)	Treated Rats: No. of Rats	Treated Rats: Mean Weight (g)	F Ratio
3	48	9.841	56	8.688	18.0
8	52	14.966	43	14.022	2.67
12	38	23.109	43	21.404	4.78[1]
15	38	29.534	37	27.485	3.72
19	33	40.341	43	36.511	5.72[1]
24	38	61.300	43	50.084	19.5[2]
29	39	80.361	45	65.844	27.5[2]
32	37	93.251	31	77.548	15.0[2]
43	37	150.23	32	122.27	19.3[2]
47	34	170.62	32	140.88	15.2[2]

[1] $P \leq 0.05$.
[2] $P \leq 0.01$.

ences and level of statistical significance tended to increase in magnitude.

The adrenals, spleen, and thymus of male rats were weighed and the results compared. Seventeen treated and 12 control rats varying in age from 35 to 53 days were sacrificed to obtain the data. No statistically significant difference was noted between the adrenals of the treated and control rats. The mean weight of the spleen per unit body weight for the controls was 3.03×10^{-4} while that for the treated rats was 3.94×10^{-4}. The mean difference was highly significant statistically ($P \leq 0.01$). The mean weight of thymus per unit body weight for the controls was 2.36×10^{-4} and for the treated rats 2.61×10^{-4}. The mean difference approached statistical significance ($P \cong 0.06$).

IV. DISCUSSION

Observations to date indicate that continuous exposure to electromagnetic fields at levels utilized in these studies have a depressing effect on growth rate of chicks and rats, and feed consumption of chicks to four weeks of age. In addition, feed utilization of chicks exposed to ELF electric and magnetic fields varied depending upon the experiment. A reduction in the weight of adrenal glands of chicks and an increase in the weight of the spleen and thymus of young rats were observed when the animals were exposed to the UHF electromagnetic field described.

The physiological and/or psychological mechanism associated with growth depression has not been resolved in these studies. It is felt that reduced growth is not the result of direct whole body heating, but from some other stimulating mechanism. It possibly could be the result of "hot spots" induced inside the chicks, similar to those observed by Guy and Korbel [12]. While this could be an explanation for the results observed, it may not apply for the experiments presented here. The VHF and UHF facilities are very low-Q cavity resonators ($Q \cong 4$) able to support only a small number of modes (particularly the VHF facility). Korbel's exposure facility had a high-Q resonance ($Q \cong 700$) and could support a larger number of modes.

Localized effects of RF currents on animal tissues cannot be overlooked. The possibility exists that localized RF currents, resulting from animal to metal wall contact could be transmitted to body tissue. These currents could be of high enough intensity to heat the tissues and cause the observed biological responses. It was not the intent of this paper to resolve this particular point.

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