BIOLOGICAL EFFECTS OF EXTREMELY LOW FREQUENCY ELECTRIC AND MAGNETIC FIELDS: A REVIEW

ANDREW A. MARINO and ROBERT O. BECKER
Veterans Administration Hospital, and the Upstate Medical Center, Syracuse, New York 13210

Reprinted from
PHYSIOLOG1CAL CHEMISTRY and PHYSICS

Volume 9, Number 2, 1977

•

GPO BOX 2044
NEW YORK, N.Y., 10001

Physiol. Chem. & Physics 9 (1977) 131

BIOLOGICAL EFFECTS OF EXTREMELY LOW FREQUENCY ELECTRIC AND MAGNETIC FIELDS: A REVIEW

ANDREW A. MARINO and ROBERT O. BECKER
Veterans Administration Hospital, and the Upstate Medical Center, Syracuse, New York 13210

INTRODUCTION

The biological effects of exposure to nonionizing radiation of radio and microwave frequencies have been studied at length.[1-6] More recently data have been reported on effects of exposure to low frequency nonionizing radiation. This paper is an attempt to review the latter material, which heretofore has not been done in any comprehensive way. We will deal only with the effects associated with exposure to fields of extremely low frequency (ELF); i.e., fields generally limited to frequencies of less than 100 Hz. Effects associated with the application of electric current via conducting electrodes are discussed elsewhere.[7-9]

With few exceptions, ELF field research did not exist prior to about 1967. Since then, however, numerous pertinent studies have appeared. Some were performed as part of an evaluation of the environmental impact of a proposed antenna (Project Sanguine).[10] Also, since the ELF range includes the power frequencies of most nations, ELF radiation is pervasively present as artificial components of the earth's electromagnetic background. This has prompted some studies of the human health consequences. But in most instances the ELF field studies were a result of increasing general interest in the effects of electricity on growth and physiology.[11-14]

We have endeavored to provide a reasonably complete review of primary ELF field biological research; related aspects of such research have been summarized elsewhere.[15-17] Electric and magnetic studies are described separately. Within each group a further distinction is drawn between acute and chronic exposure, with the dividing point generally assumed to be about 3 days. Exposure was usually accomplished through the medium of air. In some cases an aqueous solution such as seawater or nutrient media was employed. In all instances, the electric field listed herein is that to which the test organism was exposed. Epidemiological findings, and reported effects on bird orientation and plant growth, are described separately.

ELECTRIC FIELD EFFECTS

1. Acute Exposure

A variety of biological organisms, including man, have been shown to be sensitive to relatively brief exposure to ELF electric fields. Solov'ev[18] demonstrated that several

hours of exposure to 5,000 volts/cm at 50 Hz is fatal to mice and *Drosophila*. Lethal consequences have also occurred with bees.[19,20] Above 500 volts (v)/cm, bees sting each other to death; 30-500 volts/cm at 50 Hz is sufficient to change metabolic rate and motor activity. The mitotic index of liver and corneal epithelia] cells in mice was tripled following application of 200 v/cm at 50 Hz for 4 h.[21]

The influence of ELF electric fields on animal behavior has received some attention. Spittka et al .22 studied the effect of 500-700 v/cm. at 50 Hz on the drinking behavior of operantly trained rats; they showed a significant decrease in response rate when the field was applied. The operant response rate of rhesus monkeys was increased by application of 0.0035-0.35 v/cm at 7-75 Hz.[23,24] Employing classical conditioned cardiac deceleration techniques, McCleave et al.[25] showed that eels and salmon were able to perceive 0.0007-0.00007 v/cm at 60-75 Hz. The perception, which occurred only when the field was applied perpendicularly to the body axis, is the most sensitive ELF-induced biological effect yet reported. Friend et al.[26], found that amoebas exhibited changes in shape and orientation within a few minutes of the application of 10 v/cm at 1-100 Hz. The question of whether the observed effects were due to simple physical forces or arose from cellular activity was not resolved. Sazonova[27] examined the results elicited by 300-400 v/cm at 50 Hz on motor performance of rabbits. After cumulative exposure of 18 h he observed a statistically significant decrease in the rabbits' ability to do work (lift a fixed weight).

Five controlled laboratory studies have treated the interaction of ELF electric fields and human subjects. In each instance alterations in reaction time were reported. Johansson et al.[28] exposed subjects in toto to about 1,000 v/cm at 50 Hz for 75 min. The results, while suggesting decreased performance, were not statistically significant. Also employing full body exposure, at the same frequency but at field strengths ten times less intense, Hauf[29] reported that after 3 h he observed an improvement in performance. This result he attributed to a nonspecific stimulatory effect. Hauf's subjects, unlike those of Johansson et al., were electrically grounded throughout the exposure period. Hamer[30] and Konig[31] both utilized extremely weak ELF electric fields (0.01-0.04 v/cm). Konig observed decreased human performance at 3 Hz as compared to the field-free situation, and increased performance at 10-25 Hz when similarly compared. In studies during which two discrete frequencies within the range 2-12 Hz were applied consecutively to the head region of each subject, Hamer reported a decrease in performance at the higher frequency as compared to the lower frequency. Persinger et al.[32] looked for changes in the reaction time of 70 subjects as a consequence of 0.003-0.03 v/cm at 3-10 Hz applied for 40 min. Mean reaction times were not affected; however, significant sex, intensity, and frequency interactions were seen in the degree of reaction time variability.

Two animal studies describe direct effects of brief ELF electric field exposure on the central nervous system. Gann 33 subjected dogs to a small controlled hemorrhage and examined the effect of 150 v/cm at 60 Hz for 5 h on the physiological compensatory control mechanism invoked by the hemorrhage. Blood pressure and heart rate were found to be significantly different in the exposed dogs, indicating a central nervous system disturbance interfering with compensatory cardiovascular mechanisms. Lott and McCain[34] applied an inhomogeneous field of 0.4 v/cm maximum at 640 Hz to anesthetized rats. Recording from implanted microelectrodes, those investigators measured a significant increase in hypothalamic activity during the 1 h exposure period.

Short-term *in vitro* studies have disclosed ELF-induced alterations in calcium release[35] and biochemical function. In the former study, exposure of brain tissue from chicks and cats to 0.05-1.0 v/cm at 1-75 Hz for 20 min significantly reduced the release of calcium from the tissues to the surrounding medium. In the latter study, 1.55 v/cm at 60 Hz caused complete loss of biochemical function in brain mitochondria after 40 min.

2. Chronic Exposure

Behavior has been the most frequently studied biological parameter in acute exposure experiments, whereas in chronic exposure experiments growth or some other physiological aspect of a developing biological system has been studied more often.

Utilizing the most intense ELF electric field yet employed in controlled animal[37] research, Knickerbocker et al. intermittently applied to mice a vertical field of 1,600 v/cm at 60 Hz. The field was applied to male mice only for 6.5 h/day, 5 days/week, for a duration of 10.5 months. During non-exposure periods the mice were mated with non-exposed females and the offspring then reared in a field-free region. It was found that the male progenies but not the female progenies of the exposed males were smaller in weight when compared at 30, 60, and 87 days postpartum to male and female progenies respectively of the control males.

The results of Knickerbocker et al. have been confirmed and extended by Marino et al.,[38] who continuously exposed three successive generations of mice to a 60 Hz electric field. Initially, male and female mice were separated into horizontal, vertical, and control groups. Mice in the horizontal group were allowed to mate, gestate, deliver, and rear their offspring in a horizontal field of 100 v/cm. At maturity, randomly selected individuals from the first generation were similarly allowed to mate, gestate, deliver, and rear their offspring while being continuously exposed. Randomly selected individuals from the second generation were then mated to produce the third and final generation. A parallel procedure was followed both for the vertical group, three generations being produced in a vertical electric field of 150 v/cm, and for the control group, three generations of the latter being produced in the ambient electric field. In the first and second generation, males and females reared in the horizontal or vertical fields were significantly smaller than the comparable control group when compared at 35 days postpartum. In the third generation, the males exposed to the vertical field exhibited depressed body weights at 35 days postpartum.

Aberrant growth responses following chronic exposure have been reported in rats, *Dugesia* (flatworms), and *Physarum polycephalum* (slime mold). McElhaney and Stalnaker[39] intermittently applied 70, v/cm at 3 and 30 Hz to the immobilized but intact femurs of rats. Most of the exposed rats developed bone tumors whereas no tumors were seen in the control rats. In the second study,[40] two species of *Dugesia* were sectioned transversely and subjected to 3.1-4.2 v/cm at 60 Hz applied along the antero-posterior regeneration axis. In a significant number of animals the normal regeneration pattern (head anterior, tail posterior) was altered, resulting in bipolarity (the production of a head at both the anterior and posterior surfaces). In the experiments on *Physarum polycephalum,*[41,42] the investigators simultaneously applied 0.007 v/cm and 2 gauss (G) at 45, 60, and 75 Hz. At all three frequencies they observed delays in the mitotic cycle and retardation in protoplasmic streaming.

Different consequences of ELF electric field exposure have been seen in chick growth, depending on the strength of the applied field. Day-old chicks were exposed continuously for 22 days to 400 and 800 v/cm at 60 Hz.[43] Growth appeared to be affected, and gross motor activity measured after the birds had been removed from the field was reduced relative to that of the control birds. These observations led to experiments on male and female chicks separately. Female chicks were exposed continuously to 200 or 800 v/cm for the first 14 days posthatching, and body weights were obtained at 1-8 weeks of age. The mean body weight of the chicks exposed at both field strengths was greater than that of the control birds. The results, which were on the order of 5-10%, became statistically significant during the second week. Male chicks were then exposed to 400 to 800 v/cm for the first 20 days posthatching, and body weights were obtained during the exposure period. A significant enhancement in the early growth response was observed.

Giarola and Krueger[44] observed that day-old chicks exposed to a non-uniform field of maximum value 35 v/cm exhibited depressed body weights when compared to unexposed chicks. The effect became significant after 22 days at 45 Hz and 28 days at 60 Hz. In another study[45] the same group found that exposure of egg-laying hens to 16 v/cm at 60 Hz for 16 weeks caused a decrease in egg production during the first half of the test period but not during the second half. Durfee[46] exposed chick eggs during incubation, hatching, and development through 4 weeks of age to a uniform field of 36 v/cm, and found that any differences between the exposed and control birds with regard to. rate of growth were masked by the effects of crowding. In similar studies by the same group involving uniform fields of 0.01-0.10 v/cm at 60 and 75 Hz[46] and at 72-80 Hz,[47] only scattered effects on chick growth response were observed.

In vitro observations of the impact of chronically applied ELF electric fields have been made at widely different intensities. Utilizing the most intense fields on record in chronic exposure experimentation, Gann and LaFrance[48] found that the threshold of a 100% lethal effect on mammalian cells exposed for 1 week at 60 Hz in cell culture is between 2,000 v/cm and 6,000 v/cm. At 1,000 v/cm, a 12% increase in the growth of embryonic chick tibiae was seen .[49] Growth inhibition and growth acceleration were noted following exposure of chick embryo cells to 0.01-0.1 v/cm at 60-75 Hz for 1-3 days.[46]

Earlier work had revealed the ability of a magnetic field to function as a biological stressor.[50] An investigation was therefore undertaken to determine whether an ELF electric field could produce a similar response. Rats 21 to 24 days old were exposed to 150 v/cm at 60 Hz for one month in ten separate experiments.[51,52] A variety of statistically significant effects were found including depressed body weight, depressed water consumption, increased adrenal and pituitary weights, and altered serum levels of albumin, hydroxycorticosterone, and glutamic oxaloacetic transaminase. The results indicated that exposure to the ELF field produced a physiological stress response. Noval et al.[53] independently performed similar experiments at much lower field strengths and reached essentially the same conclusion. They exposed rats 30 to 35 days old to 0.005-1.0 v/cm at 45 Hz for 30-40 days. The treated rats exhibited depressed body weights, decreased levels of brain choline acetyltransferase activity, and elevated levels of liver tryptophan pyrrolase.

Mathewson et al.,[54] after exposing 49-day-old rats for 28 days to 0.02, 0.10, 0.20, 0.50, and 1.0 v/cm, reported failure to observe effects comparable to those seen by Noval et al. However, since the 60 Hz background at both the control and experimental cages was as high as 0.07 v/cm,[55] it is appropriate to regard the rats exposed to 0.02 v/cm as part of the control group for the purpose of comparing them jointly to those animals exposed at 0.5-1.0 v/cm (whereat the applied field was sufficiently greater than the background). Under that approach the data of Mathewson et al. reveal a variety of statistically significant changes including a decrease in blood glucose in three consecutive replicative experiments as well as changes in blood hemoglobin and hematocrit in two of the three experiments. Changes also occurred in at least one of the experiments in each of the following parameters: blood globulin, total lipids, triglycerides, final body weight, and red blood cell count. Neither Mathewson's nor Noval's data, nor indeed the data of any ELF investigator, support a hypothesis that the observed biological effects are dose-related.

It seems reasonable to conclude that Mathewson et al.[54] generally confirmed Noval et al.,[53] the chief difference being that the effects observed in the latter study were more severe than those observed in the former. This has led to an effort to delineate the specific differences in the respective conditions of the two studies that could arguably be responsible for the differences in results.

The Noval study was performed inside a Faraday cage formed by the steel wall construction of the facility at which the test and control animal populations were housed. The possible significance of the electrical shielding was not recognized *ab initio* and therefore was not incorporated in the experimental design of the Mathewson study. To the extent that Faraday shielding can of itself produce biological changes, it may account for the observed differences in severity between the two studies. Such effects due to shielding have been reported in humans,[56-58] guinea pigs,[59] and mice[60].

In the most thorough study of the phenomenon, Wever[56-58] isolated human subjects in underground bunkers for 3-8 weeks and measured their temperature and activity circadian rhythms. He found that subjects living in a shielded bunker exhibit periodicities in body temperature significantly different from those of subjects living in a non-shielded bunker. He also reported that desynchronization between the two rhythms occurred only in the shielded bunker. Both effects ceased when an artificial electric field of 0.025 v/cm at 10 Hz was applied, indicating that the total ambient electromagnetic environment on the one hand and the artificial field on the other influence human circadian rhythms similarly in the respects investigated. Altman and Soltau[59] exposed guinea pigs to 2.4 v/cm at 10 Hz and maintained parallel groups under Faraday conditions and under normal ambient conditions. They found that shielding produced changes in the hematocrit and the distribution of blood proteins but that both parameters returned to normal in the presence of the artificially applied field. Lang[60] exposed mice to 35 v/cm at 10 Hz and maintained parallel groups under Faraday conditions and under normal ambient conditions. Shielding produced changes in body water content, blood hemoglobin, and blood sodium levels. The effects were eliminated following exposure to the artificial electric field.

Blanchi et al.[61] found that after 1,000 h of exposure to 1,000 v/cm at 50 Hz, the electrocardiograms of mice were significantly altered. In particular, there was a lengthening of PR interval, R-wave duration, and duration of QRS complex. It has also been reported that after 192 h of exposure at 400 and 800 v/cm, chicks exhibited significantly altered electroencephalograms.[43] The spectra of the experimental and control chicks were compared in 512 frequency bands between 0-62.5 Hz. Four significantly different bands were found in the chicks exposed at 400 v/cm, while in the animals exposed at 800 v/cm seventeen significantly different bands were observed.

Early work suggested that weak electric and magnetic fields produced genetic aberrations in *Drosophila*.[62] However, subsequent work at 1 G and 0.1 v/cm[63] and at 2 G and 0.2 v/cm[64] has failed to confirm these observations.

MAGNETIC FIELD EFFECTS

1. Acute Exposure

The consequences of acute exposure at high magnetic field strengths have received some attention in connection with the phenomenon of magnetic phosphenes. Most studies of the biological effects of magnetic fields, however, have involved relatively brief exposure to low-strength fields. In such instances the effects of the fields on behavior or perception are what was usually studied.

D'Arsonval[65] first reported that a sensation of light could be produced when a magnetic field was applied to the region of the head (magnetic phosphene). Subsequently the production of magnetic phosphenes by a field of 1,000 G was reported by Thompson at 50 Hz[66] and Dunlap at 60 Hz,[67] Barlow et al.[68] described the production of magnetic phosphenes by 400-900 G at 10-90 Hz, and reported that the threshold for the effect did not change depending on whether the subject's eyes were open or shut. Recently Lovsund et al.[69] reported the production of magnetic phosphenes by a field of 150-300 G at 10-50 Hz in 13 subjects. There are presently many unanswered questions concerning the nature and the characteristics of the phenomenon of magnetic phosphenes.[70]

Utilizing 60 human subjects, Friedman et al .71 demonstrated that 3 G at 0.2 Hz superimposed on a static field of 5 G significantly affected reaction time in both males and females. When behavioral instructions to monkeys are substituted for verbal instructions to humans, however, the resulting variability in response makes it difficult to observe effects. Grissett and deLorge 72 performed reaction time measurements on 3 monkeys exposed for 10 h to 3 G at 7 and 45 Hz but failed to uncover any influence of the magnetic fields. Even chronic exposure (42 days) of the monkeys to 10 G failed to elicit an effect.[73]

The effect of full-body exposure on human cognitive and psychomotor functions was examined by Gibson and Morony.[74] They discovered that after 24 h exposure to 1 G at 45 Hz, both short-term memory and the ability to perform addition were altered.

Milburn[75] investigated the ability of human beings to perceive magnetic fields (1 G) and electric fields (2.3 v/cm). Employing a forced-choice testing procedure, he found that 2 of 48 subjects studied were able to perceive a magnetic field at 400 Hz. No subjects sensitive to the electric field were found.

Smith and Justesen[76] exposed mice to 17 G at 60 Hz and found that locomotor activity levels increased immediately upon application of the field. Persinger et al.[77] found that rats exposed for 21-30 days to 3-30 G at 0.5 Hz displayed greater activity upon removal from the field.

In a series of experiments involving 4 monkeys, deLorge utilized operant conditioning techniques to study the effect of 8.2-10 G and 0.01-0.3 v/cm at 10-75 Hz.[78-81] He failed to demonstrate that the fields were detected by the monkeys or consistently affected the stimulus control of the operant schedules. Marr[82] similarly failed to detect effects on operant behavior of pigeons and rats as a consequence of exposure to 2 G and1 v/cm at 45-75 Hz. On the basis of their work, deLorge and Marr have suggested that there are no field-induced biological effects ascertainable by operant methodology.[83] Persinger has pointed out, however, that the failure to detect effects may indicate only that the response measures studied were not sensitive to the physiological systems that mediate the stimulus effect.[84] Additionally, one would not expect that the stimulus control of the reinforcement schedule would be appreciably disrupted by such relatively weak and short-duration stimuli as those employed by deLorge and Marr.[85]

2. Chronic Exposure

Chronic exposure to low-strength magnetic fields is generally associated with some effect on growth or physiology.

Udintsev and Moroz[86] exposed rats to 200 G at 50 Hz and observed a significant increase in hydroxycorticosterone in adrenal tissue and blood plasma after 1 and 7 days of exposure. Lantsman[87] explored the effect of exposure to 200 G at 50 Hz on the phagocytic function of the reticulo-endothelial system of mice. He found that 8 h of exposure per day for 4 days inhibited phagocytotic efficiency in several organs.

Bassett et al.[88] investigated the effect of a magnetic field on the organization and strength of the repair process that occurs during the healing of a bone fracture. They applied an asymmetrically pulsed field repeating at 65 Hz with a peak value of several G to dogs that had undergone fibular osteotomies. It was found that the field accelerated the time course of the repair process. In a subsequent study[89] a magnetic field with similar characteristics was applied to patients suffering from pseudarthroses; markedly beneficial results were observed. Patients exposed for 12-16 h per day for 3-6 months achieved a success rate of 73-76% in the induction of new bone growth.

There are two other reports involving chronic exposure of human beings to a lowintensity magnetic field. Erhman et al.[90] examined the effect of a magnetic field on the amounts of medication used by several hundred patients. With regard to 10 typical medical complaints, it was found that a field of several G at 4-12 Hz brought about a reduction in the amount of medication consumed which greatly exceeded the reduction achieved with placebos. Beischer et al.[91] exposed subjects to I G at 45 Hz for 1 day. In 9 of the 10 subjects he observed a significant increase in serum triglycerides, 1-2 days after the exposure. In a subsequent study,[92] it was found that exposure of mice to 1 G at 45 Hz for 1 day did not affect the concentration of liver triglycerides.

Persinger et al.[93] exposed rats for 10-26 days to 1-30 G at 0.5 Hz and observed progressive changes in total body weight, thyroid weight, testicle weight, and water consumption. Ossenkopp[94] explored the influence of 3-12 G at 0.5 Hz on rats exposed *in utero* for 22 days. A number of physiological and behavioral effects were manifested by the pups after birth, including retardation of time of eye opening and teeth eruption, and depression of motor activity.

Giarola et al.[44] found that exposure of one-day-old chicks to 1.3 G at 45 and 60 Hz for 28 days depressed their growth rate by 9-11 % as compared to that of unexposed birds. Durfee et al. exposed chicks for 4 weeks to 8-30 G at 45-75 Hz,[46] and to 1-8 G at 72-80 Hz.[47] The results disclosed that any effect of the magnetic field on growth was negligible as compared to that caused by the effects of overcrowding.

SPECIAL TOPICS

1. Epidemiological Investigations

Soviet studies. Soviet investigators have conducted medical and physiological surveys of personnel occupationally exposed to strong electric fields emanating from components of the Soviet electrical power system.

Physical examinations of high-voltage switchyard workers revealed that 41 of 45 subjects studied presented some neurological or cardiovascular disorder during and shortly after field exposure.[95] No organic pathologies were found, but examinations did reveal instability of pulse and blood pressure, tremors of the extremities, and hyperhidrosis. Electrocardiograms showed bradycardia in 14 subjects and slowed atrioventricular conduction in 10 subjects. Laboratory studies of the peripheral blood showed mild changes from normal except for marked spherocytosis in 60% of the subjects examined. A physiological study of 54 occupationally exposed workers showed that the electric field produced functional changes in the autonomic nervous system which were related to the duration of exposure.[96] Medical surveys carried out at 16 high-voltage substations involving a total of 286 people revealed adverse effects of exposure to the electric field on the central nervous system and the cardiovascular system.[97] A physiological survey of 319 people who worked at high-voltage substations and near overhead transmission lines also revealed unfavorable changes in health.[97] Twenty-three men were exposed to power frequency electric fields while various central nervous system and cardiovascular system indices were measured; the results showed that fields stronger than 50 v/cm have an adverse effect on man.[97] A clinical study of personnel of 330 kV substations revealed a variety of harmful effects of field exposure manifested by alterations in blood pressure and electrocardiogram.[98]

Within the Soviet Union at least some occupational exposure to power frequency electric fields is regulated by a set of so-called Hygienic Rules that govern the permissible duration of exposure at various field intensities.[99] Although as early as 1970 the Soviet literature contained more than 100 reports of the influence of ELF electric fields on biological systems,[100] it appears that the Rules are based principally on the medical and physiological surveys discussed above.[99] Standards governing the exposure of agriculture workers and the general public are being developed.[101] A variety of other rules relating to the design and construction of high-voltage transmission lines presently provide some protection to both groups.[101,102]

Other studies. Strumza[103] searched the health records of 142 employees occupationally exposed to power frequency fields; he found no correlation between such exposure and the number of visits to a physician. In one of the first studies of any kind involving the biological effects of fields, complete physical examinations were given to 11 linemen who serviced 345 kV transmission lines. No effects related to exposure were found[104] nor did any such effects develop after cessation of the occupational exposure.[105] Exposure to the fields of the Project Sanguine antenna apparently did not seriously affect the health of the operating personnel106-108 or alter the metabolic rate of 5 species of soil-dwelling animals gathered from the general area of the antenna. 1O9

2. Bird Orientation

Several investigators have inquired into the possible effects of the electromagnetic near-field of the Project Sanguine antenna on bird orientation. In pilot studies,[110] it was observed that the headings of homing pigeons were slightly altered in the vicinity of the antenna. In more detailed studies, Southern[111] constructed cages on the ground directly over the buried antenna to explore the effect of the field on the instinctive directional preferences of ring-billed gull chicks 3-9 days old. When the chicks were released in the center of the cage with the antenna turned off they showed a directional preference for the southeast. When the antenna was energized the birds dispersed randomly and exhibited no mean bearing. Larkin and Sutherland[112] carried out radar tracking of individual migrating birds flying over the antenna at altitudes of 80-300 meters. They observed that when the antenna was activated or when its operating condition was being changed (off to on, or on to off) departures from straight and level flight occurred significantly more often than when the antenna was turned off. In radar tracking studies not yet fully analyzed, Williams and Williams[113] reported changes in the flight direction of migrating birds of 5-25° when the antenna was activated. No investigation has yet been made of the effect of duration of exposure nor has it been determined whether the birds sense the electric or magnetic field of the antenna, or both.

3. Plants

Remarkably little attention has been devoted to the effects of ELF fields on plants. Gardner et al.[114] studied the effect of 0.1 v/cm at 45 Hz on the growth of beans. When the seeds were planted in soil, the growth of the exposed plants was 40% greater than that of the control plants after 64 days of exposure. When the soil was replaced with a nutrient solution, however, no significant effects were seen after 37 days of exposure. The latter result has been partially confirmed by Miller,[115] who reported that 1-144 h of exposure of beans in nutrient solution to 0.1 v/cm at 75 Hz did not affect growth. Rosenthal[116] applied 0.01-0.1 v/cm and 1 G at 75 Hz to sunflower seeds planted in soil; he observed differences in seedling mortality and stem and root length between the exposed and unexposed populations.

A survey of plant life near the Project Sanguine antenna in Wisconsin suggested that the antenna near-field did not affect the normal vegetative pattern.[117] A survey of the plant life near high-voltage transmission lines suggested that the fields caused a slight enhancement of growth.[118]

DISCUSSION

Many different biological effects have been seen following exposure to ELF fields. Biological systems have exhibited a sensitivity to electric fields varying over eight orders of magnitude, and human beings have been found to be sensitive to magnetic fields as small as one G.

Acute electric field exposure is generally associated with effects on behavior. The reports linking such exposure with alterations in human reaction time are particularly worthy of attention. Chronic electric field exposure is generally found to affect growth, often producing retardation in development. Additionally, the evidence indicates that chronic exposure is a biological stressor. Acute exposure to magnetic fields has generally been studied in relation to behavioral effects or perception. Chronic exposure has been reported to be useful in human therapy.

Orthodox theory gives no definite indication of the nature of the interaction between the applied fields and the biological systems other than to rule out the possibility that the observed effects arise as a consequence of tissue heating. Employing some simplifying assumptions, it can be shown that neither ELF electric fields applied in air nor ELF magnetic fields up to at least 200 G can induce Joule heating in biological tissue. Thus the observed biological effects are not thermal in origin. Whatever molecular mechanisms may ultimately be uncovered, it is apparent that the observed effects are not energetically driven by the applied field. An analysis of the energy coupled into the biological system by the field leads to the conclusion that the role of the field is to perturb or trigger the biological system, thereby causing it to change from one state to another.[4,119] In this respect the mode of action of the ELF field is closer to that of a drug than to that of ionizing radiation. Consequently, biophysical approaches treating biological systems merely in terms of passive electrical characteristics[120,121] are inherently inadequate to explain the observed effects.

The reports of ELF field-induced biological effects have obvious environmental health implications. A typical high-voltage transmission line creates a ground level electric field on the order of 100 v/cm and 1 G. Background power frequency fields in a typical office are about 0.01-0.10 v/cm and 0.01-0.10 G.[122] Numerous investigators have reported biological effects in animals and human beings following exposure to such fields. Prediction of whether specific effects will occur in the general population as a consequence of exposure to the fields of various electrical devices depends in each instance on an evaluation of the nature and extent of the exposure and the results of the related laboratory research.

Further experimental research is imperative in view of the large element of the general population currently at risk involuntarily. Theoretical studies similarly are necessary to elucidate the underlying biophysical principles. The current dearth of such knowledge renders the process of standards-setting in general, together with related choices such as the selection of appropriate safety factors, extremely difficult.

Address all correspondence to: Dr. Andrew A. Marino, Veterans Administration Hospital, Syracuse, New York 13210.

REFERENCES

1. Z. R. Glaser, P. F. Brown and M. S. Brown, "Bibliography of reported biological phenomena ('effects') and clinical manifestations attributed to microwave and radiofrequency radiation: Compilation and integration of report and seven supplements," Naval Research and Development Command, Bethesda, Md., September, 1976; *Eighth Supplement, NTIS No. AD A029-430,* August, 1976.
2. C. H. Dodge, "Clinical and hygienic aspects of exposure to electromagnetic fields," in *Proceedings of the Biological Effects and Health Implications of Microwave Radiation Symposium, S.* F. Cleary, Ed., Bureau of Rad. Health, Division of Biological Effects, 1970, pp. 140-149.
3. Fourth report on "Program for control of electromagnetic pollution of the environment: The assessment of biological hazards of nonionizing electromagnetic radiation," *Office of Telecommunications* Policy, Executive Office of the President, June, 1976.
4. A. S. Presman, *Electromagnetic Fields and Life,* Plenum Press, New York, 1970.
5. M. S. Tolgskaya and Z. V. Gordon, *Pathological Effects of Radio Waves,* Consultants Bureau, New York, 1973.
6. S. Baranski and P. Czerski, *Biological Effects of Microwaves,* Dowden, Hutchinson Ross, Stroudsburg, Pa., 1976.
7. J. C. Keesey and F. S. Letcher, "Human thresholds of electric shock at power transmission frequencies," *Arch. Environ. Health., 21,* 547 (1970).
8. C. F. Dalziel, "Electric shock hazard," *IEEE Spectrum,* February, 1972, pp. 41-50.
9. G. L. Frenkl, K. A. Azhibayev, I. K. Mishchenko, P. D. Gorizontov and N. N. Sirotinin, *The Pathogenic Effect of Electrical Current,* Techtran Corp., Glen Burnie, Md., 1973.
10. *Navy Sponsored ELF Biological and Ecological Research Summary (Update),* PME 117 Special Communications Project Office, Naval Electronics Systems Command, Department of the Navy, Washington, D. C., February, 1977.
11. *Biological Effects of Magnetic Fields,* Vols. I and 2, M. F. Barnothy, Ed., Plenum Press, New York, 1969.
12. A. R. Liboff and R. A. Rinaldi, Eds., "Electrically mediated growth mechanisms in living systems," *Ann. NY Acad. Sci., 238* (1974).
13. J. A. Spadaro, "Electrically stimulated bone growth in animals and man: Review of the literature," *Clin. Orthop., 122,* 325 (1977).
14. P. E. Tyler, Ed., "Biologic effects of nonionizing radiation," *Ann. NY Acad. Sci., 247* (1975).
15. J. E. Bridges, "Bibliography on biological effects of electric fields," *EPRI 381-1, Final Report,* Electric Power Research Institute, Palo Alto, California, November, 1975.
16. N. Hylten-Cavallius, "Certain ecological effects of high voltage power lines," *IREQ 1160,* Institut de Recherche de I'Hydro-Quebec, Quebec, Canada, February, 1975.
17. A. R. Sheppard and M. Eisenbud, *Review of the Literature on Biological Effects of Electric and Magnetic Fields of Extremely Low Frequency,* New York University Press, New York, 1977.
18. N. A. Solov'ev, "Experimental study of the biological action of a low frequency electrical field," *Nov. Med. Priborostr., 3, 101* (1967).
19. U. Warnke, "Bienen unter Hochspannung," *Umschau 75, 13,* 416 (1975).
20. V. G. Altman and U. Warnke, "Der Stoffwechsel von Bienen (Apis *mellifica* L.) in 50-Hz-Hochspannungsfeld," Z. *Angew. Ent., 80,* 267 (1976).
21. S. G. Mamontov and L. N. Ivanova, "Effect of a low frequency electric field on cell division in mouse tissues," *Bull. Exp. Biol. Med. (USSR), 71,* 95 (1971).

22. V. Spittka, M. Taege and G. Tembrock, "Experimentelle Untersuchungen zum operanten Trinkverhalten von Ratten im 50-Hz-Hochspannungs-Wechselfelden," *Biol. Zentralbl.,* 88, 273 (1969).
23. R. J. Gavalas, D. 0. Walter, J. Hamer and W. Ross Adey, "Effect of low-level, low-frequency electric fields on EEG and behavior *in Macaca nemestrina," Brain Res., 18,* 491 (1970).
24. R. Gavalas-Medici and S. R. Day-Magdaleno, "Extremely low frequency, weak electric fields affect schedule-controlled behaviour of monkeys," *Nature, 261,* 256 (1976).
25. J. D. McCleave, E. H. Albert and N. E. Richardson, "Perception and effects on locomotor activity in American eels and Atlantic salmon of extremely low frequency electric and magnetic fields," University of Maine, *NTIS AD 778021,* 1974.
26. A. W. Friend, D. E. Finch and H. P. Schwan, "Low frequency electric field induced changes in the shape and motility of amoebas," *Science, 187,* 357 (1975).
27. T. E. Sazonova, "The effect of a low frequency electric field on the work capacity of the motor apparatus," J. *Leningrad Univ., 3,* 109 (1964).
28. R. Johansson, A. G. Lundquist, S. Lundquist and V. Scuka, "Is there a connection between the electricity in the atmosphere and the function of man?; Part 3, 50 Hz field variations," Institute for High Voltage Research, Uppsala, Sweden, 1973.
29. R. Hauf, "Einfluss elektromagnetischer Felder auf den Menschen," *etz-b, 28,* 181 (1976).
30. J. R. Hamer, "Effects of low level, low frequency electric fields on human reaction time," *Commun. Behav. Biol.,* Part A, *2,* 217 (1968).
31. H. L. Konig, "Behavioural changes in human subjects associated with ELF electric fields," in *ELF and VLF Electromagnetic Field Effects,* M. A. Persinger, Ed., Plenum Press, New York, 1974.
32. M. A. Persinger, G. F. Lafreniere and D. N. Mainprize, "Human reaction time variability changes from low intensity 3-hz and 10-hz electric fields: Interactions with stimulus pattern, sex and field intensity," *Int.* J. *Biometeorol., 19,* 56 (1975).
33. D. S. Gann, "Biological effects of exposure to high voltage electric fields, final report," *RP* 98-02, Electric Power Research Institute, Johns Hopkins University School of Medicine, Baltimore, Md., 1976.
34. J. Lott and H. McCain, "Some effects of continuous and pulsating electric fields on brain wave activity in rats," *Int.* J. *Biometeorol., 17,* 221 (1973).
35. S. M. Bawin and W. R. Adey, "Sensitivity of calcium binding in cerebral tissue to weak environmental electric fields oscillating at low frequency," *Proc. Natl. Acad. Sci. USA,* 73, 1999 (1976).
36. W. Riesen, C. Aranyi, J. Kyle, A. Valentino and D. Miller, "A pilot study of the interaction of extremely low frequency electromagnetic fields with brain organelles," 11"I, Research Institute, IITRI Project E6185, NTIS *No.* AD 748119, August, 1971.
37. G. Knickerbocker, W. Kouwenhoven and H. Barnes, "Exposure of mice to a strong AC electric field-An experimental study," *IEEE Trans. Pow. App.* Sys., PAS-86, 498 (1967).
38. A. A. Marino, R. 0. Becker and B. Ullrich, "The effect of continuous exposure to low frequency electric fields on three generations of mice: A pilot study," *Experientia, 32,* 565 (1976).
39. J. H. McElhaney and R. Stainaker, "Electric fields and bone loss of disuse," J. *Biomech.,* 1, 47 (1968).
40. G. Marsh, "The effect of sixty-cycle AC current on the regeneration axis of *Dugesia,"* J. Exp. Zool., 169, 65 (1968).
41. E. M. Goodman, B. Greenebaum and M. T. Marron, "Effects of extremely low frequency electromagnetic fields on *Physarum polycephalum," Radiat. Res.,* 66, 531 (1976).
42. M. T. Marron, E. M. Goodman and B. Greenebaum, "Mitotic delay in the slime mould *Physarum polycephalum* induced by low intensity 60 and 75 hz electromagnetic fields," *Nature,* 254, 66 (1975).
43. J. W. Bankoske, G. W. McKee and H. B. Graves, "Ecological influence of electric fields," *EPRI*

EA-178, Project 129, Interim Report 2, Electric Power Research Institute, Palo Alto, California, September, 1976.

44. A. J. Giarola and W. F. Krueger, "Continuous exposure of chicks and rats to electromagnetic fields," *IEEE Trans. Microwave Theory Techniques, MTT-22,* 432 (1974).
45. W. F. Krueger, A. J. Giarola, J. W. Bradley and A. Shrekenhamer, "Effects of electromagnetic fields on fecundity in the chicken," *Ann. NY Acad. Sci., 247,* 391 (1975).
46. W. K. Durfee, "Influence of extremely low frequency electric and magnetic fields upon growth, development, and behavior in domestic birds, Phase I," University of Rhode Island, *NTIS No. AD A007-578,* March, 1975.
47. W. K. Durfee, "Influence of extremely low frequency electric and magnetic fields upon growth, development, and behavior in domestic birds, Phase 2," University of Rhode Island, *NTIS No. AD 034526,* December, 1976.
48. D. S. Gann and T. F. LaFrance, *Effect of 60 Hertz Electrostatic Fields on Growth and Survival of Cells in Tissue Culture,* Johns Hopkins University School of Medicine, Baltimore, Md., 1974.
49. J. Watson, W. G. DeHaas and S. S. Hauser, "Effect of electric fields on growth rate of embryonic chick tibiae *in vitro,*" *Nature, 254,* 331 (1975).
50. H. Friedman and R. J. Carey, "Biomagnetic stressor effects in primates," *Physiol. Behav., 9,* 171 (1972).
51. A. A. Marino, T. J. Berger, B. P. Austin, R. 0. Becker and F. X. Hart, "Evaluation of electrochemical information transfer systems: Effect of electric fields on living organisms," *J. Electrochem. Soc., 123,* 1199 (1976).
52. A. A. Marino, T. J. Berger, B. P. Austin, R. 0. Becker and F. X. Hart, "*In vivo* bioelectrochemical changes associated with exposure to extremely low frequency electric fields," *Physiol. Chem. Phys.,* in press.
53. J. J. Nova], A. Sohler, R. B. Reisberg, H. Coyne, K. D. Straub and H. McKinney, "Extremely low frequency electric field induced changes in rate of growth and brain and liver enzymes of rats," *Compilation of Navy Sponsored ELF Biomedical and Ecological Research Reports,* Vol. III, Naval Medical Research and Development Command, Bethesda, Maryland, *NTIS No. AD A035959,* November, 1976.
54. N. S. Mathewson, G. M. Oosta, S. G. Levin, M. E. Ekstrom and S. S. Diamond, "Extremely low frequency (ELF) vertical electric field exposure of rats: A search for growth, food consumption and blood metabolite alterations," *Compilation of Navy Sponsored ELF Biomedical and Ecological Research Reports, Vol. III,* Naval Medical Research and Development Command, Bethesda, *NTIS No. AD A035954,* January, 1977.
55. N. S. Mathewson, S. A. Oliva, G. M. Oosta and A. P. Blasco, "Extremely low frequency (ELF) vertical electric field exposure of rats: Irradiation facility," *Compilation of Navy Sponsored ELF Biomedical and Ecological Research Reports, Vol. 111,* Naval Medical Research and Development Command, Bethesda, Md., NTIS *No. AD A035955,* January, 1977.
56. R. Wever, "Influence of electric fields on some parameters of circadian rhythms in man," in *Biochronometry,* M. Menaker, Ed., National Academy Science (USA), Washington, D. C., 1971, pp. 117-132.
57. R. Wever, "Human circadian rhythms under the influence of weak electric fields and the different aspects of these studies," *Int. J. Biometeorol., 17,* 227 (1973).
58. R. Wever, *ELF-Effects on Human Circadian Rhythms, in ELF and VLF Electromagnetic Field Effects,* M. A. Persinger, Ed., Plenum Press, New York, 1974, pp. 101-144.
59. G. Altman and G. Soltau, "Einfluss luftelektrischer Felder auf das Blut von Meerschweincben," *Z. Angew. Bader-U. Klimaheilk.,* 21, 28 (1974).
60. S. Lang, "Stoffwechselphysiologische Auswirkungen der Faradayschen Abschirmung und eines kunstlichen luftelektrischen Feldes der Frequenz 10 Hz; auf weisse Mause," Arch. *Met. Geoph. Biokl., Series B, 20, 109* (1972).
61. D. Blancbi, L. Cedrini, F. Ceria, E. Meda and G. Re, "Exposure of mammalians to strong 50 Hz electric fields," *Arch. Fisiol., 70,* 30 (1973).

62. W. B. Coate, "Biological effects test program pilot studies," Hazleton Laboratories, Inc., Falls Church, Virginia, *NTIS No. AD 717408,* November, 1970.

63. S. Mittler, "Low frequency electromagnetic radiation and genetic aberrations," Northern Illinois University, NTIS *No. AD 749959,* September, 1972.

64. H. Bender, "A study of the effect of ELF electromagnetic fields upon *Drosophila melanogaster,*" University of Notre Dame, *NTIS No. AD A035956,* November, 1976.

65. A. D'Arsonval, "Dispositifs pour la mesure des courants alternatifs k toutes frequences," *C. R. Soc. Biol., 3,* 451 (1896).

66. S. P. Thompson, "A physiological effect of an alternating magnetic field," *Proc. R. Soc. B, 82,* 396 (1910).

67. K. Dunlap, "Visual sensations from the alternating magnetic field," *Science, 33,* 68 (1911).

68. H. B. Barlow, H. 1. Kohn and E. G. Walsh, "Visual sensations aroused by magnetic fields," *Am. J. Physiol., 148,* 372 (1947).

69. P. Uvsund, S. E. G. Nilsson and A. Oberg, "Electromagnetic fields in Swedish welding and steel industry IV. Magnetophosphenes," *LiU-IMT-R-0013,* Link6ping University, Linköping, Sweden, 1976.

70. M. Valentinuzzi, "Theory of magnetophosphenes," *Am. J. Med. Electronics, 1, 112* (1962).

71. H. Friedman, R. 0. Becker and C. H. Bachman, "Effect of magnetic fields on reaction time performance," *Nature, 213,* 949 (1967).

72. J. D. Grissett and J. de Lorge, "Central-nervous-system effects as measured by reaction time in squirrel monkeys exposed for short periods to extremely low-frequency magnetic fields," NAMRL-1137, Naval Aerospace Medical Research Laboratory, Pensacola, Florida, *NTIS No. AD 731994,* August, 1971.

73. J. D. Grissett, "Exposure of squirrel monkeys for long periods to extremely low-frequency magnetic fields: Central-nervous-system effects as measured by reaction time," NAMRL1146, Naval Aerospace Medical Research Laboratory, Pensacola, Florida, *NTIS No. AD 735456,* October, 1971.

74. R. S. Gibson and W. F. Moroney, "The effect of extremely low frequency magnetic fields on human performance: A preliminary study," NAMRL-1 195, Naval Aerospace Medical Research Laboratory, Pensacola, Florida, *NTIS No. AD A005898,* August, 1974.

75. B. B. Milburn, "Very low frequency electromagnetic fields and behavior," *Doctoral Dissertation,* University of California, Los Angeles, California, 1971. .

76. R. F. Smith and D. R. Justesen, "Effects of a 60-Hz electromagnetic field on locomotion and aggressive behaviors of mice," presented at the *1976 URSI/APS Conference,* University of Massachusetts, Amherst, Massachusetts, October, 1976.

77. M. A. Persinger, M. A. Persinger, K. P. Ossenkopp and G. B. Glavin, "Behavioral changes in adult rats exposed to ELF magnetic fields," *Int. J. Biometeorol., 16,* 155 (1972).

78. J. deLorge, "Operant behavior of rhesus monkeys in the presence of extremely low frequency-low intensity magnetic and electric fields: Experiment I," NAMRL-1155, Naval Aerospace Medical Research Laboratory, Pensacola, Florida, NTIS *No. AD 754058,* November, 1972.

79. J. deLorge, "Operant behavior of rhesus monkeys in the presence of extremely low frequency-low intensity magnetic and electric fields: Experiment 2," NAMRL- 1179, Naval Aerospace Medical Research Laboratory, Pensacola, Florida, *NTIS No. AD 764532,* March, 1973.

80. J. deLorge, "Operant behavior of rhesus monkeys in the presence of extremely low frequency-low intensity magnetic and electric fields: Experiment 3," NAMRL-1196, Naval Aerospace Medical Research Laboratory, Pensacola, Florida, *NTIS No. AD 774106,* November, 1973.

81. J. deLorge, "A psychobiological study of rhesus monkeys exposed to extremely low frequency-low intensity magnetic fields," NAMRL-1203, Naval Aerospace Medical Research Laboratory, Pensacola, Florida, *NTIS No. AD A000078,* May, 1974.

82. M. J. Marr, W. K. Rivers and C. P. Burns, "The effect of low energy, extremely low frequency (ELF) electromagnetic radiation on operant behavior in the pigeon and the rat," Georgia Institute of

Technology, *NTIS No. AD 759415,* February, 1973.

83. J. deLorge and M. J. Marr, "Operant methods assessing the effects of ELF electromagnetic fields," in *ELF and VLF Electromagnetic Field Effects,* M. A. Persinger, Ed., Plenum Press, New York, 1974, pp. 145-175.
84. M. A. Persinger, "ELF electric and magnetic field effects: The patterns and the problems," in *ELF and VLF Electromagnetic Field Effects, M.* A. Persinger, Ed., Plenum Press, New York, 1974, pp. 275-310.
85. M. A. Persinger, "Effects of magnetic fields on animal behaviour," in *Progress in Biometeorology, H.* Johnson, Ed., Swets & Zeitlinger B. V., Amsterdam, 1976, pp. 177-182.
86. N. A. Udintsev and V. V. Moroz, "Response of the pituitary-adrenal system to the action of a variable magnetic field," *Bull. Exp. Biol. Med. (USSR), 77,* 51 (1974).
87. M. N. Lantsman, "The effect of an alternating magnetic field on the phagocytic function of the reticulo-endothelial system in experimentation," in *Problems of Hematology, Radiology and the Biological Action of Magnetic Fields, Materials of the Second Scientific Conference of TsNIL,* Tomsk, USSR, 1965, pp. 360-362.
88. C. A. L. Bassett, R. J. Pawluk and A. A. Pilla, "Augmentation of bone repair by inductively coupled electromagnetic fields," *Science, 184,* 575 (1974).
89. C. A. L. Bassett, A. A. Pilla and R. J. Pawluk, "A non-surgical salvage of surgicallyresistant pseudarthroses and non-unions by pulsing electromagnetic fields. A preliminary report," *Clin. Orthop.,* in press.
90. W. Ehrmann, H. V. Lietner, M. A. Persinger, W. Sodtke and R. Thomas, "Therapy with ELF magnetic fields," Z. *Phys. Med., 4,* 161 (1976).
91. D. E. Beischer, J. D. Grissett and R. E. Mitchell, "Exposure of man to magnetic fields alternating at extremely low frequency," NAMRL-1 180, Naval Aerospace Medical Research Laboratory, Pensacola, Florida, NTIS *No. AD 770140,* July, 1973.
92. D. E. Beischer and R. J. Brehl, "Search for effects of 45 Hz magnetic fields on liver triglycerides in mice," NAMRL-1197, Naval Aerospace Medical Research Laboratory, Pensacola, Florida, *NTIS No. AD A007514,* January, 1975.
93. M. A. Persinger, G. B. Glavin and K. P. Ossenkopp, "Physiological changes in adult rats exposed to an ELF rotating magnetic field," *Int. J. Biometeorol., 16,* 163 (1972).
94. K. Ossenkopp, "Maturation and open-field behaviour in rats exposed prenatally to an ELF low intensity rotating magnetic field," *Psychol. Rep., 30,* 371 (1972).
95. T. Asanova. and A. Rakov, "The state of health of persons working in the electric field of outdoor 400 kV and 500 kV switchyards," *Gig. Tr. Prof. Zabol. 10,* 50 (1966).
96. T. Sazonova, "A physiological assessment of the work conditions in 400 kV and 500 kV open switchyards," in *Scientific Publications of the Institutes of Labor Protection of the All-Union Central Council of Trade Unions,* issue 46, Profizdat, 1967.
97. V. Filippov, "The effect of AC electric field on man and measures for protection," presented at the *International Social Security Association Meeting,* Cologne, 1972.
98. N. N. Goncharova, V. B. Karamyshev, N. V. Maksimenko, D. K. Abramovich-Polykov, V. N. Pakova, A. S. Teslenko and V. V. Tkachenko, "Labor conditions and their effect on the functional state of the cardiovascular system in workers at high-voltage substations," in *Labor Hygiene and Biological Eflects of Radiofrequency Electromagnetic Fields,* Institute of Labor Hygiene and Professional Illnesses, Academy of Medical Sciences, USSR, Moscow, 1972, pp. 100-101.
99. V. P. Korobkova, Yu. A. Morozov, M. D. Stolarov and Yu. A. Yakub, "Influence of the electric field in 500 and 750 kV switchyards on maintenance staff and means for its protection," *Int. Conf. on Large High Tension Electric Systems,* Paris, 1972.
100. Yu. 1. Novitskiy, Z. V. Gordon, A. S. Presman and Yu. A, Kholodov, "Radio frequencies and microwaves; magnetic and electrical fields," in *Foundations of Space Biology and Medicine,* Vol. 2, Part 1, Academy of Sciences, USSR, Moscow, 1970. (National Aeronautics and Space Administration, Washington, D. C., Technical Translation TT F-14, 021, November, 1971.)
101. Yu. 1. Lyskov and Yu. S. Emma, "Electrical field as a parameter considered in designing electric

power transmission of 750-1150 kV; the measuring methods, the design practices and direction of further research," *Proceedings of the Symposium of EHV AC Power Transmission, Joint American-Soviet Committee on Cooperation in the Field of Energy, Washington, D. C., February, 1975,* United States Department of the Interior, Bonneville Power Administration, Portland, Oregon.

102. N. N. Tikhodeyev and G. Balderston, "Discussion," *ibid.*
103. M. Strumza, "Influence sur la sante humaine de la proximite des conduct d'electricite a haute tension," *Arch. Mal. Prof., 31,* 269 (1970).
104. W. Kouwenhoven, O. Langworthy, M. Singewald and G. Knickerbocker, "Medical evaluation on man working in AC electric fields," *IEEE Trans. Pow. App. Sys., PAS-86,* 506(1967).
105. H. Singewald, O. Langworthy and W. Kouwenhoven, "Medical follow-up study of high voltage linemen working in AC electric fields," *IEEE Trans. Pow. App. Sys., PAS-92,* 1307 (1973).
106. *Proceedings of the* Ad Hoc *Committee for the Review of Biomedical and Ecological Effects of ELF Radiation,* Department of the Navy, Washington, D. C., December, 1973.
107. P. E. Krumpe and M. S. Tockman, "Evaluation of the health of personnel working near Project Sanguine beta test facility from 1971 to 1972," Naval Medical Research Unit No. 4, Great Lakes, Illinois, *NTIS No. AD A023986,* December, 1972.
108. W. M. Houk, "The continuing medical surveillance of personnel exposed to extremely low frequency (ELF) electromagnetic fields," NAMRL-1225, Naval Aerospace Medical Research Laboratory, Pensacola, Florida, *NTIS No. AD A024668,* March, 1976.
109. B. Greenberg, "Sanguine/Seafarer extremely low frequency electromagnetic fields: Effect of long-term exposure on soil arthropods in Nature," University of Illinois at Chicago Circle, *NTIS No. AD A027513,* July, 1976.
110. L. C. Graue, "Orientation of homing pigeons *(Columbia livia)* exposed to electromagnetic fields at Project Sanguine's Wisconsin test facility," Bowling Green State University, *NTIS No. AD 780948,* June, 1974.
111. W. E. Southern, "Orientation of gull chicks exposed to Project Sanguine's electromagnetic field," *Science, 189,* 143 (1975).
112. R. P. Larkin and P. J. Sutherland, "Migrating birds respond to Project Seafarer's electromagnetic field," *Science, 195,* 777 (1977).
113. T. C. Williams, "A radar investigation of the effects of extremely low frequency electromagnetic fields on free flying migrant birds," Swarthmore College, *NTIS No. AD A035725,* December, 1976.
114. W. R. Gardner, R. F. Harris and C. B. Tanner, "Response of plants to extremely low frequency electric fields," Wisconsin University, *NTIS No. AD A006994,* January, 1975.
115. M. W. Miller, "Effects of extremely low frequency electric and magnetic fields on roots of *Vicia faba,*" University of Rochester, *NTIS No. AD 781333,* June, 1974.
116. G. M. Rosenthal, "Germination and early growth of sunflowers in weak ELF electromagnetic fields," University of Chicago, *NTIS No. AD A023092,* May, 1975.
117. G. M. Rosenthal, "An ecological survey of plants exposed to ELF electromagnetic fields," University of Chicago, *NTIS No. AD A035958,* November, 1976.
118. F. C. Vasek, H. B. Johnson and G. D. Brum, "Effects of power transmission lines on vegetation of the Mojave Desert," *Madrono, 23,* 114 (1975).
119. F. X. Hart and A. A. Marino, "Biophysics of animal response to an electrostatic field," *J. Biol. Phys.,* in press.
120. R. J. Spiegel, "ELF coupling to biospheres," IIT Research Institute, Washington, D. C., *NTIS No. AD A008276,* March, 1975.
121. H. P. Schwan, "Biological hazards from exposure to ELF electric fields and potentials," University of Pennsylvania, *NTIS No. AD 743480,* March, 1972.
122. F. X. Hart and A. A. Marino, "Energy flux along high voltage transmission lines," *IEEE Trans. Biomed. Eng.,* in press.

(Received May 23, 1977)