

MASTER

PROJECT RESUMES

BIOLOGICAL EFFECTS FROM ELECTRIC FIELDS
ASSOCIATED WITH HIGH-VOLTAGE TRANSMISSION LINES

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CONTRACTORS REVIEW

18-19 November 1980

U.S. DEPARTMENT OF ENERGY
OFFICE OF ELECTRIC ENERGY SYSTEMS

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DEPARTMENT OF ENERGY
Review of Research in Biological Effects From Electric
Fields From High Voltage Transmission Lines

Department of Energy Auditorium
Forrestal Building, Washington, D. C.

AGENDA

November 18, 1980

8:30 a.m.	Welcome	Thomas Garrity Martin Minthorn
8:45 a.m.	DOE Electric Field Research Objectives & Goals	Alec Bulawka
9:00 a.m.	Coffee Break	

PROJECT REVIEWS

Measurements & Special Facilities

9:15 a.m.	TVA	L. G. Akens
9:45 a.m.	SwRI	Charles Feldstone (R. Smith?)

Cellular & Subcellular Studies

10:15 a.m.	Battelle P.N.L.	W. J. Kaune F. Hungate M. Frazier
10:45 a.m.	Los Alamos Scientific Laboratories	H. Price/R. Tobey
11:15 a.m.	Univ. of Rochester	M. Miller (Miller, Brand <u>et al</u>)
11:45 a.m.	VA/Loma Linda	W. R. Adey (Lubin, Bawin <u>et al</u>)
12:15 p.m.	DISCUSSION	
12:30 p.m.	LUNCH - Choice of areas establishments	

November 18, 1980 - (Cont'd)

Physiology

General Small Animal Studies

1:30 p.m.	Battelle P.N.L.	R. D. Phillips
2:00 p.m.	VA/Syracuse	A. Marino

Neurophysiology & Endocrinology

2:30 p.m.	Battelle P.N.L.	L. Anderson
3:00 p.m.	Univ. of Rochester	S. Michaelson
3:30 p.m.	Coffee Break	

Immunology

3:45 p.m.	Battelle P.N.L.	J. Morris
4:15 p.m.	VA/Loma Linda	R. Lundak
4:45 p.m.	DISCUSSION	
5:15 p.m.	ADJOURN	

November 19, 1980

Behavior

8:30 a.m.	Argonne National Laboratory	C. Ehret
9:00 a.m.	Randomline, Inc.	A. Frey
9:30 a.m.	Univ. of Rochester	S. Stern
10:00 a.m.	Coffee Break	
10:15 a.m.	Battelle P.N.L.	R. Lovely
10:45 a.m.	VA/Loma Linda	P. Sagan
11:15 a.m.	SwRI	C. Feldstone
11:45 a.m.	DISCUSSION	
12:15 p.m.	LUNCH - choice of areas establishments	

November 19, 1980 -- (Cont'd)

Environmental Effects

1:15 p.m.

B.P.A.

Jack Lee

Modeling, Scaling & Dosimetry

1:45 p.m.

Battelle P.N.L.
Univ. of Washington

W. Kaune
A. W. Guy

2:15 p.m.

SwRI

R. Spiegel

2:45 p.m.

Battelle P.N.L.

W. Kaune

3:15 p.m.

DISCUSSION

3:30 p.m.

Coffee Break

H.V.DC.

3:45 p.m.

General Electric

M. Comber

4:15 p.m.

National Bureau of
Standards

R. McKnight

4:45 p.m.

DISCUSSION

5:15 p.m.

CLOSING COMMENTS

T. Garrity

5:30 p.m.

ADJOURN

ANALYSIS OF ELECTRIC AND MAGNETIC FIELDS ON TVA'S 500-kV TRANSMISSION LINES

Abstract Electric and magnetic field measurements have historically been measured and recorded to verify magnitudes predicted by mathematical models. Actual measurements often differ because models assume a flat terrain with no ground cover or other objects in the vicinity of the transmission line which might disturb the field and a balanced transmission system. This study will measure, record, and analyze actual electric and magnetic field magnitudes associated with the Tennessee Valley Authority's 500-kV transmission system. This data will be used to validate levels and characteristics of electric and magnetic fields in various biological and psychological studies being conducted by DOE. The effects of electric fields on the growth and development of agricultural and forest species will be investigated. Audible noises associated with various tower configurations will also be recorded and analyzed.

The project includes the following three tasks: (1) Electric and Magnetic Field Measurements and Analysis; (2) Effects on Agricultural and Forest Species; and (3) Audible Noise Measurements and Analysis. The objective of the first task is to measure, record, and analyze magnitudes of the electric and magnetic fields that exist in the vicinity of energized 500-kV transmission lines within the Tennessee Valley area. Sixteen specific categories of topography and ground cover have been identified for field measurements.

The objective of the second task is to verify and quantify the effects of electrical fields associated with TVA's 500-kV transmission lines on the growth and development of representative agricultural and forest species. This biological investigation is being conducted at a site between two 500-kV towers with individual experimental plots of each plant species located directly beneath the two outside phase bundles in the area of maximum electric field intensity. Plant species include field crops--cotton, corn, and soybeans; a small grain crop--wheat; a forage crop--white clover; and trees--loblolly pine and tulip poplar. The study will assess: germination time and percentage, plant growth and development, total crop yield, severity of insect damage, and viability of seed produced by the plants.

The objective of the third task is to measure audible noises associated with TVA's 500-kV transmission lines at approximately eight locations. Where possible, the spans selected for noise measurements will correspond to spans on which electric and magnetic fields will be measured. On each span sampled, measurements will be taken at the point of maximum expected noise (to be identified from instantaneous readings), the edge of the right-of-way easement, at one or more points along the span and at any other points which may appear useful. The audible noise investigation will include an analysis of sound pressure as a function of circuit configuration, graphs of sound pressure versus relative humidity, sound pressure versus position along the span, and sound pressure versus time. A spectral analysis will also be performed to determine the sound frequencies involved, how they might be perceived by the human ear, and how frequency may vary with humidity and other parameters.

ABSTRACT

60 HZ HIGH STRENGTH ELECTRIC FIELD EXPOSURE FACILITY

Richard T. Smith
Southwest Research Institute
San Antonio, TX

An overview is given of the design methodology and plans for the construction of a facility to provide a 60 Hz high strength electric field environment for a behavioral study of baboons. The facility will consist of an outer steel panel building with 3 interior regions: an observation enclosure, and two identical animal exposure areas. Air conditioning and filtering of the exposure areas will be provided. The electrical system will include the Power Control Room, high voltage transformer, voltage divider, electrodes, insulators, shielding screens, and grounding grid. Features of each are discussed. Individual and social cage construction, together with behavioral panel design, are discussed. Schematic cut-away drawings of the different areas and features are provided.

Electric Fields: Cellular Studies

F. P. Hungate, W. Kaune, and M. E. Frazier

Recent evaluation of the parallel plate exposure system being used to assess genetic effects of electric fields in microorganisms revealed that the electric fields could not be defined. As a result, a new system involving measurable current flow through the cell suspension has been devised. To assure that electrode effects will not interfere, agar bridges are interposed between the electrodes and cell suspension. The agar bridges contain ionic constituents identical with those in the exposure medium so that problems of ion migration are eliminated. Preliminary data on Salmonella strain TA 100 exposed in this new system indicates no significant increase in the frequency of mutations following exposure in DC fields up to 6V/m or in AC fields up to 110 V/m.

In addition, a system has been developed for the exposure of mammalian cell suspension to 60-Hz electric fields which uses an alternating magnetic field as the electric field source. The use of electrodes, either isolated from or in conductive contact with the cell suspension, is thereby avoided. Cell suspensions are held in a toroidal chamber encircling one 10-cm by 10-cm leg of a steel ferromagnetic core. A 35-turn winding on the opposite leg of the core is connected to a 60-Hz voltage source, and fields up to about 6 V/m can be generated in the cell suspension. During the past year we defined optimal conditions for cell (mammalian) growth in this exposure system and attempted to solve problems associated with obtaining representative samples at required time intervals. Using the exposure system, as presently constituted, we have generated data on the effect of AC electric fields (3.1 V/m) on the growth rates, mutation frequencies, and cell viability of Chinese Hamster ovary (CHO) cells. We have not yet observed any effects which can be attributed solely to the electric field exposures.

Effect of 60-Hz Electric Fields on the Growth of
Cultured Mammalian Cells - A Summary of
Progress During FY 1980

by

R.A. Tobey
Los Alamos
Scientific Laboratory

H.J. Price
Mission Research Corp.

K.D. Ley
Lovelace Medical
Foundation

FY 1980 research goals were to investigate the effects of 60-Hz electric fields on growth and metabolism of cultured mammalian cells (Chinese hamster cells line CHO); and to develop the apparatus necessary for these investigations. Specifically, the goals were to:

1. Design, construct and calibrate a magnetic-induction test chamber to provide a large increase in electric fields over previous test cells.
2. Repeat biological tests with the original test chamber to determine if the observed effects on cell growth rate could be attributed to 60-Hz electric fields.
3. Continue biological tests with the capacitively-coupled test chamber designed and constructed during FY 1979, to observe effects of electric fields on cell growth rate.

A magnetic-induction test chamber has been designed and constructed which provides electric fields in the cell nutrient up to approximately 2.5 volts/meter. This value is about an order of magnitude greater than obtained with the capacitively-excited chamber designed last year.

The original test chamber used in the first biological tests (FY78) seemed to indicate a change in cell growth rate with applied electric fields. This chamber, while biologically adequate, was not electrically adequate. That is, the electric-field coupling to the nutrient solution was inefficient, and the apparatus produced corona. Since the biological results observed with this test chamber could not be repeated with the newer electrically adequate test chamber, tests were repeated on apparatus similar to the original chamber. It was concluded that changes in growth rate were not attributed to electric field in the nutrient solution.

A complete series of biological tests were conducted using the electrically adequate test chamber designed and constructed in FY 1979. No changes in growth rate have been observed.

Studies during FY 1981 will include investigation of test chambers to obtain even higher electric fields in the nutrient solution, and biological tests with the new magnetic-induction test chamber.

60 Hz Electric Field Parameters Associated with the
Perturbation of a Eukaryotic Cell System

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Dominique Robertson, and David A. Dooley

Departments of Radiation Biology and Biophysics,
and Electrical Engineering¹,
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The objective of the research is to elucidate a mechanism whereby an electric field affects a multicellular system. The hypothesis being tested is that there must be a significant induced membrane potential, relative to the cells' normal resting potential, to perturb the system. A dielectric approach to the study of tissues indicates that at extremely low frequencies (ELF) the largest local induced fields will occur in cell membranes. Each cell consists of a highly conducting cytoplasmic core surrounded by a very thin insulating membrane; thus, the entire voltage drop across the cell will occur in the membrane. The magnitude of the induced potential is approximately the product of the extracellular applied field (V/m) and the cell diameter (μm).

The results of previous research with 60 Hz electric field-exposed roots of Pisum sativum indicated through dose response relations, a threshold field strength of 290 V/m for growth perturbation; the induced membrane potentials were calculated to be of the order of 3 - 8 mV. Additional data continue to support the hypothesis. Roots were chronically exposed to 60 HZ electric fields (215 to 430 V/m) and current densities (1.5 to 2.7 mA/cm²). Adjustments of the exposure medium's conductivity (0.035 to 0.14 S/m) allowed for distinction between a field or current induced perturbation in root growth rates. Inhibition of growth rates was directly related to the magnitude of the applied field and not the current density. Additional results indicate (1) a narrow range between induced membrane potentials which alter normal cellular function and those which arrest it, (2) a perturbation to cell progression at fields which reduced root growth rate, and (3) an ability to recover from an e-field induced growth rate reduction.

The significance of the data is that a) the response of pea roots to electric fields is consistent with a cell membrane related mechanism, and b) the electric field strengths necessary to produce these growth effects could not be obtained if air were a series part of the path between the source and the roots.

Experiments with ELF-exposed mammalian cell suspension cultures (L5178Y and P-388 mouse lymphoma cells) and Physarum polycephalum (slime mold) are in startup and will be used to test further the above hypothesis.

DEPARTMENT OF ENERGY CONTRACTORS REVIEW CONFERENCE

Abstract - John S. Brand
University of Rochester
ELF Project

Electric Field Effects on Subpopulations
of Cells Isolated from Bone

There is currently great interest in the application of local electric fields to the therapy of bone fracture non-union. This project is designed to test the effects of low energy electric fields on the proliferation and metabolic function of separate populations of cells from neo-natal rat bone. Two cell preparations, maintained in short-term primary culture, have been demonstrated to exhibit features of either bone forming or bone resorbing cells.

Changes in rate of DNA synthesis, determined by assay of incorporation of ³H-Thymidine into DNA were observed in cultures of osteogenic cells exposed to a field of 2100 V/cm. Short term exposure (6-30 minutes) was inhibitory while longer exposure (24 hours) to the field produced a stimulation. Stimulation of ³H-thymidine incorporation during a 2-hour pulse at the end of a 24 hour exposure period required that the cells remain in the field during the thymidine pulse. If cells are exposed for 22 hours and removed from the field during 2-hour pulse labeling period, there is no difference from control cultures. In these preliminary experiments, stimulation of DNA synthesis during the longer exposure period was not observed in the cell populations containing osteoclastic cells. These results suggest a difference in at least one response of two separate cell populations to electric field exposure.

When these results have been confirmed by measurement of total cell DNA content, the time course of the effect will be studied in more detail as well as the response to varying field strength. It will be important to determine whether the magnitude of response is related to field strength or if there is a uniform effect above a threshold voltage.

SEN LIN-LIU and W. R. ADEY
Jerry L. Pettis Memorial Veterans Hospital
Research Service
Loma Linda, California

ABSTRACT

Effect of ELF Modulated 450 MHz Field
on Calcium Efflux from Rat Synaptosomes

Interaction between low level EM radiation and nervous tissues was studied at subcellular levels. Synaptosomes from cerebral cortex of male rats were incubated at 22C for 5 min, and in a solution containing $^{45}\text{Ca}^{2+}$ for 10 min. They were then applied to millipore filters and perfused at a rate of 1 ml/min for 60 min with a physiological solution at 34C. Perfusate collected at 1 min intervals was assayed by liquid scintillation counting. During perfusion, synaptosomes were exposed to 450 MHz fields at 0.5 mW/cm² and sinusoidally amplitude modulated at ELF. Exposure started 15 min after the onset of perfusion. The time course of $^{45}\text{Ca}^{2+}$ efflux follows a three-phase exponential curve. In a preliminary analysis, each curve is normalized according to the first point of the second phase (which is about 13 min after the onset of perfusion). For each exposure condition, all curves are then averaged. Four conditions are compared at present; they are controls without any field exposure, CW and 16 and 60 Hz modulation. Before onset of the fields, all four groups show the same efflux characteristics. After the exposure, CW, 60 Hz modulation and control are not distinguishable. However, 16 Hz modulation produced a shift of the perfusion curve, probably arising from an increased amount of calcium in the second phase.

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ABSTRACT

$^{45}\text{Ca}^{2+}$ Efflux from Synaptosome Pellets Exposed
to ELF Pulsed Magnetic Field

Synaptosomes in suspension were incubated in $^{45}\text{Ca}^{2+}$ and centrifuged into pellets. The pellets were washed once and allowed to stand in 1.0 ml of physiological solution for studies of time course of efflux at various temperatures and effects of 325 μsec pulses at 80 Hz on efflux. Pellets were left in solution for varying times up to 25 min, and the radioactivity in the solution and pellets were then assayed by liquid scintillation counting. The percentage of efflux (%E) is calculated as:

$$\text{Radioactivity in solution} / \text{radioactivity in (solution + pellet)} \times 100$$

With the same pellet size, the time course of efflux was constructed at 22C and 32C. The normal two phases of efflux were distinguished, the fast phase being highly temperature dependent, and the slow phase less so. Beginning of the slow phase was determined to be 15 min at 22C and 7.5 min at 32C. By varying the pellet size from large to small, the fast phase can contribute 14 to 40% of the efflux. The rate of fast phase efflux at 32C is about twice that at 22C. This temperature dependence suggests that the calcium binding and dissociation process at the surface membrane is involved. Its dependence on pellet size suggests that a diffusion process is important in the pellet. The temperature insensitivity of the slow phase suggests involvement of transmembrane calcium movement.

Efflux for 15 min at 22C and for 7.5 min at 32C was studied. Test tubes containing synaptosome pellets were exposed between a pair of Helmholtz coils. Similar preparations were placed at least 2m away from the coils as controls. At both temperatures, field exposure caused a 5% reduction in $^{45}\text{Ca}^{2+}$ efflux at pellet size corresponding to %E higher than 20% at 22C and lower than 20% at 32C. Thus, the effect showed up in smaller pellets at 22C and larger pellets at 32C. This dependence on pellet size may be attributed to a difference in calcium diffusion at these two temperatures, since the effect lasts for only a short time. Because no metabolic substrate and no ATP were provided in the efflux medium, it is probable that energy-independent calcium binding to surface macromolecules is modified by the field.

SUZANNE BAWIN and W. R. ADEY
Jerry L. Pettis Memorial Veterans Hospital
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Loma Linda, California

ABSTRACT

Studies of Cellular Responses to ELF Fields - Hippocampal Slice Preparation

Rat hippocampal slices are being used in the laboratory to study the effects of ELF and RF electromagnetic fields on the electrochemical excitability of the central nervous system. We have accumulated baseline data on the behavior of the slice under physiological conditions, through observations of spontaneous activity and responses of the CA₁ pyramidal cells to stimulation on an intrinsic fiber pathway (the Schaffer collaterals). Electrophysiological responses such as long-term hyperpolarization, long-term potentiation, and epileptic activity in the hippocampal slice, are critically dependent on the calcium concentration in the bathing medium, and are impaired at calcium levels lower than 1mM. Enkephalins have recently been shown to increase spontaneous activity and amplitude of population spike response to Schaffer collateral stimulation in CA₁ pyramidal cells. Therefore, we have studied the effects of low and high calcium concentrations on these excitatory effects as preliminary steps in assessing the possible role of 60 Hz sinusoidal electric fields on cellular excitability. Our results indicate that at low concentrations of enkephalin (100 to 200nM), the increased excitability of the pyramidal cells is modulated by the amount of calcium present in the solution (1, 2 or 4mM).

Repetitive electrical stimulation (trains of pulses at 15 and 100 Hz) has been shown to decrease the extracellular calcium concentration and increase potassium concentration in the vicinity of the pyramidal cell layer, and we have previously described changes in ⁴⁵Ca²⁺ efflux from isolated brain tissue exposed to ELF and ELF modulated RF fields. Therefore, the level of excitability induced in the pyramidal cells by the opioid peptide could also be modulated by exposure of the tissue to weak bath currents at frequencies between 15 and 100 Hz.

We have started the second phase of this investigation by comparing the effects of localized (Schaffer collaterals) and bath electrical stimulation in three slices previously treated with enkephalin (1 μM). Both stimulations induced large temporary increases in the responses evoked in two slices, but this effect was abolished in the third experiment by the presence of Naloxone (5 μM) in the solution. This indicates that the effect seen in the treated tissue is specific to the previous exposure to enkephalin.

SUZANNE BAWIN and W. R. ADEY
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Loma Linda, California

ABSTRACT

Influence of Pulsed Magnetic Fields on Calcium Binding in Isolated Brain Tissue

Previous studies in this laboratory have shown sensitivity of freshly isolated chick cerebral hemisphere to weak, extremely low frequency (ELF) electric fields (10-60 V/m in air) and to microwave fields (0.5-1.5 mW/cm² in air), amplitude-modulated with ELF signals. We now report studies with weak pulsed magnetic fields on identical tissue preparations. The magnetic field generator was designed for stimulation of bone healing by Bassett and Pilla (Orthopedic Service, Columbia University). The field has a pulse repetition frequency of 80 Hz. The waveform is a 325 μ sec square wave followed by a 5 msec tail of opposite polarity, and peak field intensity is 20 gauss, producing tissue gradients of 1-2 mV/cm and a current density between 1 and 10 μ A/cm².

The isolated brains were tested at room temperature and at 35C. The physiological solutions used in these studies contained (in mM): NaCl:155; KCl:5.6; CaCl₂:2.16; glucose:10; NaHCO₃:either 2.4 or 10, and MgCl₂:either 0 or 1.2. Results at room temperature (23C) were widely scattered in control and experimental tissues, and no significant trend developed in the final analysis of the data. By contrast, the percent efflux (⁴⁵Ca in the supernatant divided by the sum of ⁴⁵Ca in solubilized brain and in supernatant) from brains exposed to the pulsed magnetic fields at 35C was significantly lower than control and sham exposed brains, in the two bathing solutions tested here. Moreover, addition of hydrogen ions (pH 6.8) to the solution facilitated the field interactions with the tissue in a significant manner (Bawin et al, 1980). Similar facilitation of field effects by hydrogen ions has also been observed in chick brains exposed to 450 MHz fields, modulated at 16 Hz (Bawin, Adey and Sabbot, 1978).

Similar experiments are now performed using magnetic fields pulsed at 60 Hz. After completion of this first series of studies, the biological effects of magnetic fields pulsed at frequencies between 5 and 80 Hz will be assessed in terms of ionic binding and neurotransmitter release in the thin tissue slices from rat hippocampus which are currently studied electrophysiologically in this laboratory.

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ABSTRACT

Magnetic Field Effects on Electrophysiologic
Function of Aplysia Neurons

Alternating magnetic fields may be used to induce electric currents in tissue with the assumption that effects would be the same as when produced by electric fields. However, the magnitude of magnetically-induced electric currents depends on the area of the exposed tissue and its position in the body or position within the experimental container. Apart from these considerations for the location of maximal currents, microscopic current loops of very small magnitude exist at the cell periphery and within the cell throughout the exposed region. Because patterns of current flow due to an AC magnetic field are very different from those due to an electric field, magnetic field exposures may stimulate distinctive biological responses. Study of magnetic field effects is important because of the concern for environmental AC magnetic fields and because of the increasing use of these fields in experimentation. In part, this increase occurs because magnetic fields may be used to introduce substantial current densities without invasive electrode techniques that are frequently troublesome, either from electrolytic problems or from artifacts of high voltage stress.

Although there is growing evidence for localized ferromagnetic structures in some animals, the magnetic permeability of the biologic tissues is essentially the same as that of free space and a direct magnetic interaction is not presumed in these studies. We have designed a magnetic field exposure system suitable for use in an electrophysiological study of Aplysia pacemaker neurons during field exposure. Several neurons of the abdominal ganglion ("white cells") spontaneously produce action potentials despite relatively complete independence from synaptic input and without external stimulation. Other pacemaker neurons of the abdominal ganglion ("L7, L10, L9," etc.), although more richly connected to other cells of the ganglion, also behave as endogenous pacemakers.

We have observed several phenomena in both classes that occur with delayed onset after the application of small electric current densities that correspond to electric fields of 1 to 4 mV/cm: firing rates show increased variability, membrane potentials exhibit hyperpolarizing shifts, and some cells exhibit paroxysmal activity after several minutes of field application. With stronger fields of 20 mV/cm, effects occur more promptly and resemble those obtained by injection of current into the cell body, but definite phase relation between the applied current waveform and action potential generation that exists for intracellularly injected AC currents is absent when extracellular currents are employed.

Because only a few parts per million of the current in the extracellular medium cross the cell membrane, the transmembrane potentials due to extracellular current of the magnitude used in these studies are very much smaller than the transmembrane potentials created by current injection into the interior of the cell. We estimate that the transmembrane currents due to extracellular currents are only 10^{-2} to 10^{-4} of the transmembrane currents that occur during intracellular injection. It appears that the observed alterations in membrane excitability are not due to an overall change in membrane potential and may be related to local changes at particular sites on the membrane.

R. A. LUBEN*, M. CHEN* and D. ROSEN*
A. A. PILLA** and W. R. ADEY***

ABSTRACT

Pulsed electromagnetically induced currents, designed for electrochemical cell surface activity, have been shown to be effective therapeutically for the healing of recalcitrant bone fractures. This study attempts to elucidate the cellular mechanisms involved by determining induced current effect on the regulatory activity of the bone-destroying parathyroid hormone (PTH). Results show a 90-99% inhibition of adenylyl cyclase response to PTH and of PTH-specific decreases in collagen synthesis and alkaline phosphatase. Fluoride-activated cyclase was unchanged, suggesting that induced current blocked PTH action either by a modification of the PTH receptor or by alteration of receptor-cyclase coupling.

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**Bioelectrochemistry Laboratory, Columbia University, New York, New York

***Jerry L. Pettis Memorial Veterans Hospital, Loma Linda, California

Biological Effects of Electric Fields on Small Laboratory Animals

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This project was started in 1976. The first year was devoted to designing and building systems for exposing large numbers of rats and mice to 60-Hz electric fields. Once these systems had been built, appropriately characterized and shown to be free of artifacts, our next goal was to determine what organ systems, if any, were affected by exposure to 60-Hz electric fields. This goal was achieved by conducting a broad and comprehensive series of experiments by an interdisciplinary research team. We examined, in detail, 24 major areas in the biological sciences. Rats and mice were exposed to 60-Hz electric fields up to 130 kV/m for durations as long as four months. No significant effects were found in the following major areas:

- Metabolic status and growth
- Organ and tissue morphology
- Brain morphology
- Cardiovascular function
- Serum chemistry
- Reproduction
- Prenatal growth and development
- Teratology
- Bone growth
- Peripheral nerve function
- Humoral and cell-mediated immunity
- Susceptibility to viral infection
- Cell and membrane function
- Illness/malaise
- Cytogenetics

Statistically significant effects of electric field exposures were observed in the following areas:

Bone fracture repair - retardation
Neonatal development - earlier neuromuscular development
Neuromuscular function - faster recovery from muscle fatigue
Endocrinology - lower serum testosterone level
Hematology - increased WBC in F₁ and increased RBC in F₃
in 3-generation mouse study
Neurochemistry - depression of circadian rhythm of pineal
gland melatonin level and SHAT activity
Urine volume and chemistry - increased volume and nore-
pinephrine level
Sympathetic nervous system - increased excitability of the
superior cervical ganglion
Behavior - preference by rats to stay out of the field at
 ≥ 90 kV/m and in the field at ≤ 50 kV/m during the sleeping
period

Most of the effects we have observed are subtle and small in magnitude. Many of the effects appear to be related directly or indirectly to possible effects of exposure on the nervous system. In fact, it is likely that many of the effects we have observed are secondary to chronic stimulation of the animal by the field.

Our research effort has shifted from that of a screening study to an in-depth investigation of nervous system functions, with emphasis in behavior, neurochemistry, neurophysiology and dosimetry. Our current and future research in these areas will focus on:

Relationship of effects to field strength and duration of exposure (dose-response relationship)

Recovery from observed effects

Fundamental understanding of observed effects

Fundamental understanding of interaction of field with animal (dosimetry)

Biological significance of observed effects

BIOLOGICAL EFFECTS OF 60-HERTZ FIELDS

Andrew A. Marino, Ph.D.

Abstract

The multigeneration (MG) and fracture-healing (FH) models are two animal systems that we have developed to evaluate the effects of power-frequency fields. In a MG study, various growth and reproductive indices are measured over three generations; the extent of healing is measured in a FH study. We previously reported that 3.5-15 kv/m (MG) and 5 kv/m (FH) -- but not 1 kv/m -- induced biological effects in the exposed animals; a 0.5 kv/m (MG) study is now in progress. Our future plans include:

1. A characterization of the electrical environment in the exposure system including direct measurements of both the perturbed fields, and the transient and steady-state currents that are associated with the watering system;
2. Replication of the MG study at either 3.5 or 0.5 kv/m;
3. Evaluation of the effect of 0.1-1 gauss (MG & FH);
4. Determination of the synergistic interaction due to simultaneous electric and magnetic fields (MG & FH);
5. Development of the stress hypothesis as a mechanism of interaction with emphasis on mathematical modeling.

Effects of ELF Exposure on Neural and Endocrine Systems of Rodents

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P.O. Box 999
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A comprehensive study has been conducted to screen for effects on rodents of acute and chronic exposure to 60-Hz electric fields. An emerging pattern of potential effects has been observed in specific areas of the nervous system.

Neurophysiology: Detailed neurophysiologic tests of myelinated (sciatic) and unmyelinated (vagus) nerves from exposed and sham-exposed rats did not show any consistent changes as the result of electric field exposure. Transmission of impulses between nerves (in synapses) was investigated using the superior cervical sympathetic ganglia from rats that had been exposed (100 kV/m) or sham-exposed for 30 days. Characteristics of the postsynaptic compound action potential, conduction velocity and high-frequency-induced fatigue were not altered by exposure of the rat to the electric field. However, the conditioning-test response curves of exposed rats were shown to be significantly higher than those of sham-exposed rats. It appears that exposure to 60-Hz electric fields may promote increased excitability of nerve synapses.

Studies designed to assess the effect of exposure on neuromuscular function examined: twitch characteristics, chronaxie, tetanic potentiation, post-tetanic potentiation, and recovery from fatigue. Only fatigue recovery in soleus (slow twitch) muscle showed a statistically significant difference between exposed and sham-exposed animals, with recovery rate being significantly faster following electric field exposure.

Endocrinology: Following 120 days of exposure of young male rats to 60-Hz (100 kV/m) electric fields, no consistent statistical differences from controls were seen in serum concentrations of follicle-stimulating hormone, leutinizing hormone, prolactin, thyroid-stimulating hormone or corticosterone. Serum levels of testosterone were significantly lower in exposed animals than in sham-exposed controls.

Neurochemistry: Pineal glands from exposed and sham-exposed rats (30 days, 65 kV/m) were examined for melatonin content as well as serotonin-N-acetyl transferase (SNAT) activity. A difference between day and night values of melatonin was observed in sham-exposed animals, whereas, no significant difference was seen in exposed rats. Electric fields exposure also affects circadian SNAT activity, with a statistically significant difference between exposed and sham-exposed rats at night.

It appears that the diurnal rhythm in both pineal melatonin and SNAT are strongly altered by exposure to the electric field.

Future plans: Follow up studies are underway to examine in greater detail areas where exposure effects have been observed.

- 1) Pineal chemistry: a replicate of the enzyme study and a more comprehensive examination of serotonin pathways is in progress.
- 2) Experiments to investigate pineal gland/superior cervical ganglion interactions are planned.
- 3) Development of the visual evoked response of rats exposed in utero and before weaning is being studied.
- 4) A study to examine the recovery characteristics of the conditioning-test response is scheduled.
- 5) Neurotransmitter levels in several regions of the brain will be measured.

The Influence of 60 Hz Electric Fields on Physiologic Regulation in the Rat.

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Objectives of these studies are to assess the mechanisms of subtle physiologic reactions resulting from or reported to result from exposure to 60 Hz electric fields. Neuroendocrine/neurotransmitter (NE/NT) assays are utilized as indexes of neurophysiologic and neurochemical stability. This is predicated on the concept that if 60 Hz electric fields produce biological perturbations, they will be manifested by functional changes in regulatory systems of the body of which the central nervous system is the main integrator through the hypothalamus and NE/NT pathways. Our approach addresses the following questions: 1) Can continuous or intermittent exposure to 60 Hz electric fields produce alterations in NE/NT integration? We are especially sensitive to the fact that subtle intrusions into the experimental design e.g., hormonal changes due to handling or other external stimuli, could contribute to results that lead to erroneous conclusions. 2) Is the sensitivity to 60 Hz electric fields altered during variable physiologic (i.e. diel cycles; hormonal interventions) or pathophysiologic (hypertension, diabetes, etc.) states? 3) If there are weak field effects (as reported by some investigators), do these have any physiologic significance and can the mechanism be elicited from examination of the finely tuned integrated pathways of NE/NT control?

To accomplish these objectives we are building and characterizing a 60 Hz exposure system based partially on that currently in use at Battelle Pacific Northwest and the behavioral studies facility in our own department. While awaiting completion of construction of the facility we have utilized the latter chamber to carry out some studies, the results of which we can now report.

Male (230-250 g) Long-Evans rats were exposed 1 or 3 hours to a 100 kV/m 60 Hz continuous or interrupted electric field. Serum for corticosterone, prolactin, growth hormone and thyrotropin levels and brains for catecholamines and serotonin assay were obtained immediately after cessation of exposure.

To date measurements of corticosterone, growth hormone and prolactin do not indicate any change in serum levels as a result of exposure to 100 kV/m electric fields. Analysis of other hormones and the neurotransmitters are in progress.

Since these studies will focus partially on integration of NE/NT stability in relation to behavioral responses, in the future we will use field strengths at, above, and below the detection level in the same strain of rat under exposure conditions similar to those of the behavioral studies. Exposure durations will be 1, 3 and 24 hours; 1 week and 1 month. Assessment of possible synergy, additivity, or amelioration with pharmacologic agents or pathophysiologic states will be undertaken.

In the next year we will assess the possible influence of diel variations on hormone levels, the influence of agonists and antagonists of dopamine (apomorphine, haloperidol) and opiates (morphine, naloxone) and the influence of a brain serotonin releasing agent such as fenfluramine on responsiveness of the rat to a 60 Hz field. We will test the difference between continuous and intermittent exposures for indications of habituation or cumulative reaction to repetitive stimuli. In relation to the studies on behavior we will include similarly food restricted rats in some of our exposures to permit better definition of the animal model for such studies as well as indication of possible influence of nutritional status on susceptibility to electric fields.

Effects of 60-Hz Electric Fields on the Immune System

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In vivo and in vitro assays of immune system components and functions have been conducted to define possible alterations in cell-mediated immune parameters and host resistance following exposure of animals to 60-Hz electric fields.

Cell-mediated immunity was measured in mice exposed for 30 to 120 days to 100 kV/m electric fields with delayed (keyhole limpet hemocyanin, KLH) and contact (dinitrofluorobenzene, DNFB) hypersensitivity assays. No consistent statistical differences were observed between exposed and sham-exposed mice. Mitogen-stimulation responses (in vitro assays that correlate with cell-mediated immunity) of spleen cells from mice exposed for 30, 90, 120 and 150 days were not statistically different from sham-exposed controls. Furthermore, the in vitro stimulation responses of spleen cell cultures (spleens obtained from immunized mice after 30 or 120 days of exposure) with the challenging antigen (KLH) were not altered by the exposure of the animals to electric fields.

The influence of electric fields on disease resistance was assessed in chickens using a virus model. In this system, chickens were exposed (or sham-exposed) from 3 to 10 days of age, injected with a leukemia virus and exposed for another 25 days. No significant difference in the incidence of leukemia or weight gain was observed between exposed or sham-exposed chickens.

In summary, data collected to date on various humoral and cellular components of the immune system have not shown any consistent statistical differences between exposed and sham-exposed animals.

During the coming year, immunological studies will concentrate on the possible effects of 60-Hz electric fields on natural immunity parameters and possible interactive effects of electric field exposure with known leukemogenic agents (chemical and physical).

ABSTRACT

The Effect of 450 Megahertz Nonionizing Microwave Radiation
on Cell-Mediated Cytolytic Immune Response

The effect of a weak 450 MHz nonionizing microwave field (1.5 mW/cm^2 , sinusoidally modulated at either 16 or 60 Hz) on the cell-mediated cytolytic immune response was evaluated in the following manner: an established T killer cell line from C57 black animals termed clone 8-CCTL was maintained in culture by the addition of RPMI 1640 and T-cell growth factor obtained from PHA-stimulated rat spleen cell cultures. These cytolytic T-cell killers (clone 8) are specific for allogeneic kill across the H-2 histocompatibility locus in mouse. The target for cytolytic kill is a DBA 2 mastocytoma tumor line established by Brunner et al. some years ago.

The assay system is that described by Brunner and now in wide use. Briefly, clone 8 cytolytic killer lymphocytes at a ratio of 4 killer lymphocytes to 1 DBA mastocytoma target cell are mixed together in RPMI 1640 containing 50% T-cell growth factor. The DBA 2 mastocytoma target cells have been previously labeled with ^{51}Cr . Following 4h of coincubation with T killers, chromium released in the supernatant is an indication of cytolytic kill due to clone 8 killer cells. The standard assay is conducted over a 4h period.

Different experiments have been completed that show influences of an ELF modulated 450 MHz field on this cytolytic process. First, clone 8 cells were exposed to the field with 60 Hz modulation 4h prior to cytolytic assay. An average from three experiments (each with 6 replicates) showed $22 \pm 8\%$ reduction in initiating cell-mediated lysis when cells had been exposed for 2h to the field 4h prior to their cytolytic assay. If clone 8 killer cells were exposed to 60 Hz modulated microwave for 4h while the cytolytic assay was being conducted, there was a $23 \pm 8\%$ reduction in the cytolytic kill capacity of these cells. $19.4\% \pm 2\%$ of this reduction can be accounted for in cells exposed only during the first 2 of the 4h-assay. When exposed only during the last 2h of the assay, there was only an $8.3 \pm 2\%$ reduction in cytolytic capacity.

To test for a possible "window" with respect to modulation frequency, cells were also exposed to 450 MHz radiation at 16 Hz during and prior to their cytolytic assay. Cells exposed to 16 Hz modulation for 4h during the cytolytic assay showed no detectable suppression of cytotoxicity. Cells exposed to 16 Hz for 2 to 4h prior to cytolytic assay also showed no significant suppression of cytotoxicity, indicating that a specific window may exist at or about 60 Hz, but not at 16 Hz.

We have also tested recoverability from this microwave-induced suppression of cell-mediated cytolytic reaction, by exposing clone 8 killer cells to a 60 Hz modulated 450 MHz field for periods from 2 to 4h, followed by reculture for various periods. Following the recuperative reculture period, these cells were again assayed. They showed a clear time-dependent recovery curve. At 4 and 8h following exposure cells still showed a 22 to 24% reduction in cytolytic capacity. However, at 16 to 24h they had fully recovered.

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Effect of High-Voltage Fields on Ultradian, Circadian and Infradian Functions in Rats

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OBJECTIVES

The objectives of this program are to investigate the effects of ELF fields (10-240 Hz) on the ultradian, circadian and infradian regulatory aspects of physiological and behavioral patterns in rats by determining the occurrence of phase or period changes in ongoing circadian rhythms during continuous and intermittent exposure to electric fields, and of internal desynchronization by improperly phased exposures to electric fields. When changed patterns are observed, concomitant neurochemical measurements will be made in order to evaluate underlying mechanisms and hazards.

ACCOMPLISHMENTS

Under a variety of circadian and ultradian exposure protocols, Charles River rats have been exposed to 60-Hz horizontal electric fields at field strengths up to 100 kV/m. The exposure facilities are of the residential variety that permit long-term and continual observation in situ before, during, and following field exposure. These consist of 10 units that incorporate features to measure and record automatically core temperature, activity, body weight and gain, and the number of times in which a bar is pressed to gain a food reward in a behavioral paradigm. Continuous exposures, and circadian-intermittent exposures have produced no significant effects upon circadian period lengths, or in causing circadian phase changes in the above mentioned functions. Significant levels of hyperactivity have been observed in two groups of young rats (2-4 mos.) exposed intermittently (0.5 h on, 0.5 h off, 4 x) to 67 kV/m during the inactive phase of their circadian cycle. In addition, significant hyperactivity has been measured in a small group of rats exposed as above but at only 33 kV/m. However, no subsequent changes in circadian functions have been observed following any exposure paradigm tried to date.

SIGNIFICANCE

The possibility of phase-coupling by membrane reception-transduction of ELF energy to the circadian clock pathway (and therefore to long-term effects) must be investigated because of 1) Wever's observations that this can happen, albeit @ 10 Hz and 2) because of the close association between manifest behavior, neurochemistry and circadian clock-chemistry. Disturbances of the circadian oscillation can have profound effects on mental health and longevity, and the boundary conditions and thresholds for potential zeitgebers must be defined.

PLANS FOR NEXT YEAR

Attempts to influence circadian phase and period by the 60 Hz field will continue by means of an operant conditioning paradigm that couples the field ON condition with circadian phase and food reward. In another series, perturbations of circadian functions will be attempted in the variable frequency domain (10-20 Hz) in order to 1) prove the Wever assumption and 2) if verified, to learn the optimum phase relations for circadian perturbations and 3) apply these at 60 Hz. Appropriate neurochemical assay procedures will be applied when called for.

Work supported by the U.S. Department of Energy under contract No. W-31-109-ENG-38.

Effect of High-Voltage Fields on Energy Metabolism,
Motor Activity and Body Temperature in Mice

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OBJECTIVES

The objectives of this study are to describe changes in physiological and behavioral measures in response to high voltage ELF exposure at 60 Hz. Diurnal patterns of oxygen consumption, carbon dioxide production, motor activity and telemetered body temperature are established by a continuous transduction and analysis system. Recordings during and after field exposure are compared with the pre-exposure pattern to determine field effects.

ACCOMPLISHMENTS

A variety of exposure schedules have been used, but initial efforts have concentrated on a series of four hour-long exposures during the inactive phase of the daily cycle. Effects have been studied using floating conditions, with the animals in plastic-bottomed cages at 1 kV potential, and grounded conditions, with mice resting on grounded metal floorplates. Gas and activity measures were significantly increased over baseline levels during the first exposure hour in both grounded and floating conditions with 100 kV/m, 60 Hz fields. The response was relatively brief; no increases were measured in any exposure hour except the first. The arousal response was greater and activity levels remained increased longer when animals were exposed in the grounded condition, but none of the effects lasted longer than two hours. We have begun to study arousal responses in grounded animals exposed at lower field strengths. Thus far, twelve mice have been exposed at each voltage level for 75, 50, 25 and 10 kV/m. Arousal responses at 75 and 50 kV/m were comparable to the 100 kV/m floating condition responses. Four of the mice exposed at 25 kV/m were aroused by the field, but the amplitude of the response was small in comparison to higher voltages. One mouse was active at field onset at 10 kV/m.

SIGNIFICANCE

We have described a transient arousal response to high voltage ELF field exposure, and determined that the threshold for the response is approximately 25 kV/m. The findings emphasize the importance of exposure schedules and suggest that intermittent exposures may be more disruptive of metabolic systems and behavior than continuous exposures.

PLANS FOR NEXT YEAR

We will vary the inter-exposure interval to determine the recovery time necessary to insure arousal responses with each ELF field exposure, then determine the long-term effects of exposures separated by that interval. We also plan to study perception thresholds, aversive or rewarding properties, and effects on other sensory modalities of high voltage ELF exposure. In addition studies of the effects of electrical noise in ELF fields are planned.

Work supported by the U.S. Department of Energy under contract No. W-31-109-ENG-38.

DETERMINATION OF NEURAL, BEHAVIORAL, AND REPRODUCTIVE EFFECTS OF 60 HZ FIELDS

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ABSTRACT

We plan to initiate experiments with 60 Hz fields in November after a hiatus of a year. Experiments will be done to determine threshold field strengths for several behavioral measures of neural function, measures such as the conditioned emotional response and timing. Another aspect of the work will involve assessment of a hypothesis on mechanism. Since the hypothesis that the dopamine systems of the brain are involved in electromagnetic field effects has been shown to have predictive power in guiding some EM experimentation, it will be directly assessed with 60 Hz fields both physiologically and with a simple sensitive behavioral test. A histofluorescence technique designed to identify catecholamine distribution in the brain will be used. The tail pressure response behavioral technique will also be used since it has been found to be indicative of dopamine function in the brain. The other aspect of the work involves assessing the possible prenatal exposure effects of 60 Hz fields on later neural and behavioral function.

Behavioral Effects of 60 Hz Electric Fields:
I. Detection of 60 Hz Electric Fields by Rats
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Objective: The purpose of this program is to identify and study behavioral effects produced by exposure to 60 Hz electric fields. Our immediate objectives are to determine the detection threshold of the field by rats, and to identify the mechanisms of detection.

Accomplished in 1980: Six rats were trained to emit a specified response in the presence of a vertical 60 Hz electric field but not in its absence. The probability of emitting the response was directly related to the field strength. Preliminary analyses show that the threshold (i.e., the field strength at which the rat emitted the response during 50 percent of the trials) was approximately 5 to 8 kV/m. The range between almost no detection to almost 100 percent detection of the field was approximately 5 kV/m.

Plans for 1981: We shall continue to study detection of the electric field. Visual observation of the rats suggested that stimuli associated with being close to, or making contact with, the plastic chamber might have controlled, at least partially, detection of the field. By modifying or removing the chamber for some rats, and by clipping the vibrissae and hair of others, we are attempting to study the mechanism(s) of detection.

Significance and implications: Our assessment of the significance of a behavioral, or other, effect of exposure to a 60 Hz electric field, in terms of potential hazard, may be more adequate if we can relate such a result to the sensory sensitivity, and mechanisms of sensitivity, to the field. We initially intended to study the effects of exposure to uniform 60 Hz electric fields. We now believe that stimuli, electrical or other, are produced by action of the field on the chamber, and that these stimuli may significantly affect the observed performances. This conclusion is based on our visual observations, electrical measurements of the field near the chamber, and reports in the literature. The functional significance of the chamber has not been studied systematically. In our studies we are attempting to eliminate factors introduced by the chamber, by eliminating the chamber itself. Since, however, some behavioral responses to the electric field may depend on the presence of other material, we must be prepared to study these phenomena as well.

Behavioral Effects of 60-Hz Electric Field Exposure

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The main purpose of the behavioral studies now extant at Pacific Northwest Laboratory is to identify, assess and evaluate possible effects of 60-Hz electric fields on the behavior of laboratory animals during and subsequent to exposure.

A taste aversion paradigm was used to determine whether exposure produces illness/malaise in rats. Rats exposed to a variety of field strengths (effective field strengths of 130, 65 or 32.5 kV/m) for three hours following consumption of 0.1% sodium saccharin in water failed to show differential intake of saccharin solution whether assessed by one-bottle consumption (5 trials) or a two-bottle preference test between plain water and saccharin flavored water. From these data one concludes that, at least with these short exposure durations (five 3-hour sessions), malaise/illness in rats is not induced by electric field exposure. Positive controls treated with Cyclophosphamide validated the protocol employed.

In a second series of investigations we attempted to determine if a synergistic/interactive effect could be demonstrated by treating animals with a minimal dose of Cyclophosphamide (5 mg/kg) and concomitant exposure to the electric field. Unlike the former studies, however, we exposed rats for five hours as opposed to three to determine if a longer exposure duration might also render rats "ill."

Thirty-two rats were randomly assigned to one of four cells in a 2 x 2 factorial design. Factor one represented exposure to a 60-Hz electric field (130 kV/m) or sham-exposure for five hours. Factor two consisted of injecting rats with saline (placebo) or Cyclophosphamide (5 mg/kg). The drug treatment was administered immediately after 20 minute access to 0.1% sodium saccharin in water given every other day for five days. Electric field exposure followed drinking by 30 minutes. On alternate days the rats had access to distilled water for 20 minutes. Following the five conditioning trials, the rats were given a final water "recovery" day which was followed 24 hours later by a 20 minute two-bottle preference test between water and sodium saccharin in water.

The one-bottle tests failed to reveal any effects of electric field exposure per se, but did reveal a slow cumulative effect of repeated administration of the 5 mg/kg Cyclophosphamide. Similarly, the two-bottle preference test revealed a clear cut taste aversion developing for the Cyclophosphamide treated rats. Interestingly, the Cyclophosphamide

effect appears to be less robust in exposed rats (62% saccharin preference for exposed rats vs. 38% for sham-exposed). During the course of the study, specifically the second trial, a lighting failure (outage) occurred in the exposure room and this seemed to greatly potentiate the particular days treatment. As a result of this possible serendipitous finding, we extended the study as a pilot investigation, after the aforementioned five training trials and subsequent preference test, with one change in the procedure. The electric field exposures were carried out in the dark while all other conditioning parameters remained the same. The results of these two extra conditioning trials produced slight enhancement of the early effect. There was an even clearer suggestion of an interaction between the lighting condition when it is varied with the other two major parameters (Cyclophosphamide and electric field exposure) when data are blocked across exposure vs. sham-exposure conditions.

Our plans for the immediate future are directed primarily at resolving the synergy/interactive possibility of Cyclophosphamide when administered prior to electric field exposure. A planned 4 x 2 factorial experiment should help clarify whether possible synergy exists and also provide some idea as to whether it is a simple matter of additivity of different stimuli or, on the other hand, an effect attributable to the interaction of electric field exposure with the condition of lighting independent of other factor manipulations. In addition, we plan to behaviorally characterize and quantitate our earlier findings of selective "preference" or "aversion" for 60-Hz electric fields by rats. The findings to date, while provocative, tell us little about the behavior in question. Specifically, the finding that rats do have "preference" at ≤ 50 kV/m or "aversion" at > 90 kV/m suggests that they will work a manipulandum to enter or exit the field. If such is the case, behavior can be easily quantified by increasing the work demand (reinforcement schedule) to determine the extent to which an animal's preference is to be in or out of the field.

Perhaps the most important behavioral work element for FY 81 will be our attempt to identify, by the "preference"/"aversion" paradigm, sensitive populations of animals, (i.e., animals most perturbed by field exposure). It may well be the case that by identifying such populations, if they exist, we will be able to explain why so many electric field "effects" are evanescent. For example, exposing 30 rats in a subchronic study where 10 of the rats are adversely motivated, 15 unaffected and five appetitively motivated, may well mask real effects that are manifest in only one group.

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ABSTRACT

Behavioral Research

The behavioral component of the research program at the VA Hospital, Loma Linda is intended to measure the effects of 60 Hz electric field exposure on operant performance on a number of schedules related by their time-dependent characteristics. In each case, the goal is to both identify the nature of changes in performance and to determine the behavioral mechanism associated with the observed changes.

During the past year, a major part of the work in the behavioral area has been directed toward the establishment of a computer facility of sufficient power to perform the real-time data acquisition and analysis required for the behavioral research and to as well serve the rest of the non-ionizing radiation research program here. This system includes a PDP-11/70 with 1.3 Mb of on-line disk storage, magnetic tape and a full complement of real-time peripherals for experiment control. This system was delivered in October of 1979. During the first six months that the system was on site, all software required for real-time data acquisition was completed and all special interface hardware completed.

During the past year, a two-test-chamber exposure facility was completed and subsequently evaluated by NBS. Data collection was then begun in an experiment that measures the performance of M. nemestrina on a DRL5-1h2.5 schedule. Two subjects have just completed three test sessions at each of six voltages (0 V/m, 10 V/m, 50 V/m, 100 V/m, 500 V/m, 1000 V/m, all rms). Data from these subjects will be analyzed in terms of their micro-structure. A number of measures based on the subjects' bouts (or runs) of responding on the test schedule and the subjects' performance during those runs indicate substantial changes in performance in the 100 V/m condition, in contrast to the other conditions. It is hypothesized that the observed changes in performance result from small changes in the variability of the subject's IRT (interresponse time) distribution. These small changes, it will be argued, are amplified by a strong interaction with the contingencies imposed by the DRL-1h schedule, resulting in much larger changes in performance measures that include run length, response rate during runs and reinforcement rate during runs. The magnitude and sign of the change in performance appear to be determined by the interaction of the reduction in variability and the DRL-1h contingency.

ABSTRACT

A PRELIMINARY STUDY OF POSSIBLE EFFECTS OF HIGH INTENSITY 60 HZ ELECTRIC FIELDS ON NON-HUMAN PRIMATE BEHAVIOR

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A preliminary study of the effects of high intensity 60 Hz electric fields on baboon behavior has been conducted. Since the preliminary study was undertaken without certain controls, the results, even though they are statistically significant, must be viewed as anecdotal information useful for hypothesis formation. Groups of baboons were exposed to 30 kV/m, 60 Hz, vertical electric fields for an average of 4.5 hours per day for 23 days. Juvenile baboons were trained on various operant schedules (vigilance, fixed-ratio, spaced-responding and matching-to-sample) prior to exposure. Young adults lived in a small social group. Data was gathered before, during (both with fields on and off) and after exposure.

Some subjects evidenced statistically significant field effects. One vigilance subject evidenced a greater variability of response time to correct stimuli when fields were on--a result that could be related to arousal level. The social animals had lower frequencies of locomotion with fields on by the end of the exposure period--another result that suggests a field effect on arousal level. Animals manipulated their own skin more with fields on but the effect disappeared by the end of the exposure period--a result suggesting adaptation. Inter-animal contact was more frequent with fields on especially social approach and contact. Inter-animal avoidance was greater with fields on at the beginning of exposure, but was less with fields on by the end of exposure. In general, the animals interacted more with fields on and primarily in non-agonistic manners. Animals did not alter their postures in response to fields (a possible means of altering surface field intensities). No obvious deleterious effects were observed.

Environmental Studies of Transmission Lines 1/
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Since 1974 the Bonneville Power Administration (BPA) has sponsored several studies to obtain information on environmental effects of transmission lines, i.e., studies of plants and animals in natural environments. BPA markets power generated by Federal hydroelectric dams in the Pacific Northwest. The BPA transmission system includes over 19,000 km of lines of which over 4,600 km are 500 kV.

The BPA environmental studies program considers effects of transmission line construction, maintenance, and operation. Special emphasis is placed on identifying possible effects of corona and electric and magnetic fields because of continued interest in these subjects.

The most comprehensive study sponsored by BPA is being conducted by Battelle Northwest Laboratories at the site of an 1100-kV prototype transmission line (Contract No. 14-03-6033N). Principal Battelle investigator is Dr. Lee Rogers. Studies at the prototype site near Lyons, Oregon began in 1976. They involve natural vegetation, crops, wildlife, cattle, and honeybees. During 2 years of study with electric field strength comparable to BPA 500-kV lines (7-8 kV/m), the only verified effect of the field was leaf tip burn on some trees close to the line. In 1979 and 1980 the electric field strength was increased for test purposes. Cattle have shown no obvious reluctance to graze or drink in electric fields up to 12 kV/m, the highest level studied. A possible subtle effect on crop growth was seen at 12 kV/m. Results of the 1980 crop studies with a field strength of 15 kV/m are now being analyzed. Based on preliminary 1980 results the threshold for effects on established honeybee colonies in commercial type hives appears to be between 8 and 12 kV/m. Effects on bees include increased propolization, decreased broods, increased adult mortality, and decreased honey production. Effects appear to be related to induced current flow through the hives possibly resulting in shocks to bees. The 1980 studies include evaluating a method for mitigating adverse effects of high electric fields on bees.

Another subject of growing interest is the effect of transmission lines on birds in flight. Here the concern is primarily that birds at times collide with lines. Most collisions with 500-kV lines appear to be with overhead groundwires rather than conductors. It is not clear whether corona or electric and magnetic fields are factors influencing collision potential during periods of poor visibility. BPA is currently sponsoring two studies of bird/transmission line interactions. One involves a new 500-kV line that crosses waterfowl flyways on a National Wildlife Refuge on the Columbia River. The line was energized in October 1980. Contractors are the Western Interstate Commission for Higher Education (WICHE) (Contract No. DE-AC-79-80BP17109) and Willdan Associates (Contract No. DE-AC-79-80BP21135). The second study is an investigation of methods for mitigating bird collisions with transmission lines (WICHE Contract No. DE-AC-79-80BP23018). It began in September 1980 and includes removing sections of overhead groundwire in high bird use areas.

1/ Summary of presentation at the DOE Review of Electric Field Effects Research, November 18-19, 1980 in Washington, D.C.

AC E-FIELD DOSIMETRY

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We have previously shown that when a grounded human, pig, and rat are exposed to the same 60-Hz electric field, the fields at the surfaces and induced inside the bodies of the subjects are greatly different, in some cases by as much as a factor of 10. The purpose of this project is to provide detailed measurements of the actual fields experienced by exposed humans and other species. These measurements are needed so that biological data, obtained using rats, mice or other animals as subjects, can be used in the assessment of possible risks to humans exposed to 60-Hz electric fields. To obtain these dosimetric measurements, two methods are being pursued:

Direct Measurements of Induced 60-Hz Electric Fields in Human and Animal Models.

A technique has been developed at the Pacific Northwest Laboratory for the direct measurement of the greatly attenuated electric field induced inside the body of a conducting human or animal model exposed to an external, 60-Hz electric field. A small probe detects, by conductive coupling, the potentials at two slightly separate points. The sampled signals are passed to a remote differential amplifier through a small shielded cable. Electric fields as low as 0.5×10^{-3} V/m have been measured in saline solution. Molds to hold saline solutions in various shapes are machined from polyurethane foam (measured 60-Hz dielectric constant = 1.04). As an overall test, a hemi-spheroidal volume (15.2-cm height x 5.1-cm-radius base) was cut in a 13.5-cm x 14.0-cm x 16.5-cm-high polyurethane block, and the resulting mold, placed on a ground plane, was filled with saline (conductivity = 0.021 S/m). An electric field of 1.57×10^{-2} V/m was measured inside this grounded model when it was exposed to an uniform, 60-Hz, 11.0-kV/m electric field. The close agreement between this value and the theoretical value of 1.60×10^{-2} V/m proves the feasibility of the technique. The next step is to make realistic molds of humans and various animals and to characterize the fields induced in them for various conditions of exposure.

Determination of Induced 60-Hz Electric Fields and Currents in Models Using a Radio-Frequency Technique.

Current distributions in various tissue geometries exposed to 60-Hz electric fields were determined at the University of Washington by an analog method using phantom models exposed to UHF electric fields.

Electric field intensities of sufficient strength to generate heating patterns in the phantom tissues were produced in a high-Q resonant cavity fed by a 1 kW source. The specific absorption rate (SAR) of energy patterns were determined from the resulting temperature distributions within the model by a thermograph camera and converted to the 60-Hz current density patterns. Experiments on phantom models of prolate spheroids and spheres exposed in the center of the cavity showed that the induced uniform current distributions agreed well with theoretical values obtained from the quasi-static analysis of similar objects exposed to 60-Hz fields. Measurements on three different scale models of man indicated that the current distributions were identical regardless of size, which helped to confirm the validity of the approach. The maximum induced current densities were found in the neck, knee and ankle regions. When models in contact with a ground plane were exposed, the current increased as predicted by the image effect. These experiments demonstrate that the cavity exposure could indeed simulate both free space and ground plane 60-Hz exposure conditions. When scale models of miniature swine were exposed with their feet in contact with the ground plane, the induced currents were concentrated in the thigh, ankle and foot.

ABSTRACT

COMPARATIVE MODELING OF MAN AND BABOON IN 60Hz ELECTRIC FIELDS

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In order to extrapolate 60 Hz electric field effects on experimental animals (baboons) in terms of equivalent effects on man, scaling relations for the induced current densities have been developed by utilizing advanced computer modeling techniques. Humans and baboons were modeled by a large number of small cubical blocks that were arranged to obtain the best possible fit to the contour of the object. Internal current densities for the models were calculated by the solution of an integral equation for the induced polarization at the center of each block. Numerical results are given for an erect human with the arms down at the side and for a baboon in a quadrupedal, bipedal, and sitting stance.

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DOSIMETRY OF DIFFERENT 60-HZ ELECTRIC-FIELD EXPOSURE SYSTEMS

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It is important that biological data collected in different laboratories exposing animals to 60-Hz electric fields be comparable across different exposure systems and across different species. In making comparisons, it is necessary to relate electric field strengths used in one laboratory to those used in another. This cannot be done simply on the basis of the unperturbed field strength present before the introduction of the experimental subjects, because the actual fields experienced by an animal depend not only on the unperturbed field strength but also on its species and the type of exposure system. This paper will focus on dosimetric differences between different types of exposure systems.

The most significant dosimetric differences between 60-Hz electric-field exposure systems appear to be (1) the orientation of the subject relative to the unperturbed electric field, (2) whether single or multiple animals are exposed, (3) whether animals are singly or multiply caged, (4) whether experimental subjects are grounded or ungrounded, and (5) whether subjects can affect their exposure by changing their behavior. Available experimental and theoretical data relating to the effects of these factors will be reviewed. Based on this review, we make the following conclusions: (1) Exposure systems using single, grounded animals are characterized by controlled and relatively easily quantifiable dosimetry. (2) Interactions between animals exposed in close proximity to each other significantly reduce their coupling to an applied electric field. (3) In multianimal exposure systems using singly caged and grounded subjects interactive effects between animals can be controlled and are fairly easily quantified. (4) The dosimetry of exposure systems using multiply caged animals is variable and dependent on animal behavior. (4) The dosimetry of exposure systems using ungrounded animals appears to be much more difficult to quantitate. (5) Systems using ungrounded animals exposed to a horizontal field simulate most closely the normal orientation of a human when exposed to a 60-Hz electric field, but the subjects can behaviorally change their coupling to the field by at least a factor of five.

Dosimetry must be an integral part of any comparison of biological data obtained using different exposure systems or animal species. Currently, quantitative comparisons can be made only for singly caged, grounded subjects. Before such comparisons can be made using other types of exposure systems, dosimetric quantification is required.

DOE CONTRACTORS REVIEW MEETING

STUDY OF ELECTRIC FIELD AND ION EFFECTS
OF HVDC TRANSMISSION LINES
(PROJECT UHV, GENERAL ELECTRIC COMPANY)
ABSTRACT

This new 4-year (1980-83) program has three primary objectives:

- 1) to measure and define the electrical environment in the vicinity of high voltage dc transmission lines
- 2) to be able to predict the electrical environment of future hvdc lines
- 3) to provide bio-effects researchers with the information on hvdc transmission line environments that they require to properly perform their research.

The research is an extension of that carried out under a previous DOE program at Project UHV (1977-79). For the new program, the research facilities have been expanded to provide the capability of investigating the performance of bipolar lines up to ± 1500 kV.

It has been established that reduced-scale test facilities (such as a conductor test cage) cannot adequately model the behavior of full-scale transmission lines. This is a result of the space charge-effect; the space charge which exists between conductors of opposite polarity and between conductors and ground significantly modifies the electric field in space, this modification being geometry dependent. Consequently, much of the research attention has been focused on tests of full-scale line geometries.

Tests have been performed on several conductor configurations in the ± 250 kV to ± 400 kV range (including the "Square Butte" ± 250 kV configuration) and also on one configuration in the ± 900 kV to ± 1200 kV range. The tests are providing information related to the effects of line geometry, voltage, and weather parameters on ground level electric field and ion current density. There is a clear indication that each of these variables has a significant effect on the overall performance of a hvdc transmission line.

To further help in the understanding of the phenomena, similar line tests, on other configurations and at other voltage levels, will be performed throughout this program. Additional research will be conducted in the following areas:

- Aerosols: atmospheric aerosols passing close to a hvdc transmission line can become charged through contact with corona-produced ions; instrumentation to measure the practical extent of this effect is being developed.
- Shielding methods: means of reducing ground level fields and currents through shielding (e.g. grounded wires, trees, and other objects) will be investigated.
- Corona on objects at ground: in a sufficiently high field, objects at ground potential (e.g. grass, trees, other objects) can go into corona, a possible environmental concern; the conditions required for such an occurrence will be investigated.

DC FIELDS AND ION MEASUREMENTS

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The NBS program is concerned with developing methods for evaluating and calibrating instrumentation for use in measuring the electric field and various ion-related electrical quantities in the vicinity of high-voltage (HVDC) transmission lines and in apparatus designed to simulate the transmission line environment.

A parallel plate apparatus designed to produce electric fields in the presence of space charge has been evaluated and used to determine the response of two vibrating plate electric field meters and a field mill to electric fields greater than ~ 6 kV/m with attendant current densities up to $\sim 3.5 \mu\text{A}/\text{m}^2$. The original one dimensional model used to predict the operation of the system has been modified to take account of field penetration into the parallel plate region of the apparatus. The field mill which appears to be free of significant errors associated with incident current has been used to verify predictions of the modified theory. Both vibrating plate meters studied display some errors associated with the presence of sufficiently large ion current incident on the sensing element.

Errors associated with lack of coplanarity of Wilson plate sensors with the ground plane have been investigated using both ac electric fields and dc electric fields with space charge in a parallel plate apparatus. Significant errors were observed for both guarded and unguarded sensor plates. The magnitude of the error depends on spacing above the ground plane. Agreement between ac and dc measurements was good except for an unresolved discrepancy for the unguarded sensor.

A low speed air flow facility has been constructed to produce a volume containing space charge which can be used as a source of ions for evaluating and comparing instruments designed to measure various ion related properties. Studies were made of losses at the inlet structure of parallel plate ion counters and of the efficiency of an "absolute filter" for removing ions from an air stream.

Model calculations to estimate errors associated with self charge of off ground field measuring instruments were completed and design considerations for a rotating instrument with spherical symmetry were begun.

Efforts during the coming year will consider operation of the parallel plate system over a wide range of parameters and the investigation of different ion measuring instruments using the low speed air flow facility. A new area of interest will be in the measurement of the mobilities of ions produced in the air flow facility.