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.R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

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HIGH-VOLTAGE HEALTH EFFECTS STUDIES

*Overhead high-voltage transmission is the most effective way to move large amounts of electric energy over long distances. Higher line voltages improve transmission efficiency and cut costs (*EPRI Journal, *June/July 1977, p. 7). However, accompanying the higher voltages and currents applied to the lines are higher electric and magnetic fields that reach the ground beneath the lines. Public concern about whether these fields affect health has grown rapidly in this decade, and EPRI is sponsoring a number of projects to resolve this question.*

Before new high-voltage lines can be sited and rights-of-way granted, utility representatives must appear at public hearings to convince local authorities that no evidence exists linking the electromagnetic environment to serious health or safety risks. One of the key triggers of this concern was a Soviet report to the 1972 CIGRE Conference in which a variety of maladies suffered by switchyard workers were attributed to electric fields. Since then, several articles in the popular literature have quoted the assertions of the Soviets and other researchers that 60-Hz electromagnetic fields pose a serious health risk. Much of the research cited in these articles was not carried out in well-engineered exposure systems, nor were the studies validated by replication. As a result, the scientific community and the electric utility industry have felt the need for research programs that would methodically address the issue of how 60-Hz electromagnetic fields interact with biological matter.

In 1974 EPRI initiated its high-voltage health effects subprogram, an extension of activities begun earlier by the Edison Electric Institute. At that time the IIT Research Institute (IITRI) in Chicago undertook a state-of-the-art literature review to help provide direction for the program (RP381). This review, originally published in 1975, has been updated in a recent EPRI report (EA-1123), which outlines areas that warrant immediate research.

Effects on cardiac pacemakers

One such area concerns the question of whether electromagnetic fields from overhead transmission lines can interfere with the operation of implanted cardiac pacemakers. Almost all pacemakers in use today are R-wave inhibited; that is, they are quiescent until the heart misses a beat, at which point they pulse the heart once and then await the next missed beat. If interference is picked up, the pacemaker will revert to a mode in which it pulses the heart independently of any other stimuli. Cardiologists agree that reversion is not in itself hazardous.

To investigate the pacemaker question, IITRI undertook a project to mathematically model the interaction between electromagnetic fields and pacemakers and to test pacemakers implanted in baboons (RP679-1, RP679-2, and RP679-3). The IITRI research showed that reversion is the worst-case consequence of 60-Hz irradiation and that under most conditions, reversion is not probable. Similar findings were obtained when the interaction between pacemakers and the electromagnetic environment of a high-voltage dc converter station was studied. Although there was a high probability that reversion would be initiated at certain locations in the converter facility, it was determined that a patient would not be endangered. These studies are soon to be published by EPRI. The final phase of the pacemaker research is under way at the University of Rochester, where human pacemaker patients are being exposed to transmission line environments under constant medical supervision (RP679-6).

Other major research projects are examining the effects of electric fields on a variety of living systems: honeybees, crops and other plants, birds, and large and small mammals.

Effects on honeybees

Honeybees are being studied for three basic reasons. First (and central to research needs), the beehive contains a highly organized and integrated caste society in which each individual is programmed from conception to death (roughly two months) to perform specific functions. If power line environments produce biological alterations, such changes could stand out clearly in the complex but highly formal chain of beehive events. Second, each beehive contains upward of 50,000 bees, an enormous sample size. Third, a number of commercial apiaries, for convenience of space, are located beneath transmission lines, and beekeepers are concerned about whether this environment will affect honey production.

Bioconcern (RP934-1) and an IITRI engineering team (RP934-2) have developed an approach to studying beehives under the 765-kV Commonwealth Edison Co. line near Joliet, Illinois. Preliminary results indicate that hives situated in the field gain less weight, have lower brood production, and may fail to survive the winter. As a defensive mechanism, the exposed bees tend to deposit a resinous substance called propolis around the hive entrance. Before concluding that electric fields per se are responsible for these effects, researchers must exclude the possibility that the bees are receiving unavoidable minishocks (a sensation similar to that which one receives after walking across a carpet on a dry day and touching a doorknob). These minishocks would arise from field-induced voltages on the hive parts and, if present in sufficient magnitude, would likely be stress-provoking. Whether fields alone or minishocks are responsible for the observed effects awaits resolution.

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Effects on plants

Since 1974, engineers at Westinghouse Electric Corp., in collaboration with biologists at Pennsylvania State University, have sought to determine what effects electric fields have on seedling plants (RP129 and RP1064). The issue of risk to plants is important because transmission lines are often sited over valuable farmland. Researchers at PSU have studied 85 species of seedling plants, including crops of economic importance, such as corn, wheat, and alfalfa. They observed that other than limited damage to the tips of pointed leaves, the seedlings were not affected by fields up to 50 kV/m, roughly five times the maximum field strength found beneath the largest lines. Only pointed leaves are susceptible to damage because the electric field is enhanced at the leaf tip. If enhancement exceeds a threshold, the air around the tip ionizes, a condition known as corona. With the onset of corona, the tip of the leaf is singed but there is no further damage.

It is still unknown whether maturing and fully grown plants are affected. A greenhouse containing overhead electrodes (9 ft high) is now under construction at EPRI's Waltz Mill facility. Species such as corn, wheat, oats, alfalfa, and soybeans will be allowed to germinate and grow in the electric field. Scheduled for completion in 1981, this research should provide important information to utilities and farmers.

Effects on birds and small animals

The PSU small-animal studies, under the same project, analyzed the electroencephalograms (EEGs), electrocardiograms (ECGs), body weights, and gross motor activities of domestic chicks that had been exposed to 40- and 80-kV/m fields for three weeks. No adverse effects were observed in the EEGs, ECGs, or body weights, but gross motor activities were reduced by 28% in the fourth week of life, that is, after exposure had terminated. There is as yet no explanation for this result, although it may be related to an ability to perceive the field through feather stimulation. PSU researchers have demonstrated that pigeons can perceive fields as low as 10–20 kV/m. This area of investigation will continue.

Another experiment at PSU examined how corticosteroid levels in mouse blood were affected by 25–50-kV/m fields. (Corticosterone is secreted by the adrenal cortex into the blood when an animal or human is under stress.) After a brief (45-min) increase in steroid secretion when the mice were introduced to the field, the levels dropped to normal for the remaining six weeks of the experiment. The researchers feel that the brief increase in steroid does not represent true stress as much as it reflects a short period of adaptation to a newly perceived stimulus.

Interpretation of animal studies and extrapolation to humans must be tempered by the realization of an important fact: to simulate human exposures in small laboratory animals, larger fields must be generated. This is because the field is distorted when biological matter is introduced into it, and the extent of the distortion is dictated by the size and shape of the subject. Thus, an 80-kV/m exposure to a chick (or a mouse) is roughly equivalent to human exposures of 5 kV/m under actual conditions.

The animal work at PSU is now turning to the investigation of field effects on developing chick embryos. An exposure facility with a capacity for 1600 eggs is in place, and experiments are under way. Chick eggs are considered excellent for studying electric field effects because the dose to each egg is relatively easy to calculate (field enhancement is very predictable on the egg's rounded surface) and because the embryo is a system undergoing rapid cell division, thus allowing investigation of whether fields interfere with the cell cycle.

At Battelle, Pacific Northwest Laboratories an interdisciplinary team has constructed and implemented exposure systems for small (mice, rats) and large (Hanford miniature swine) animals. The small-animal research is being supported by DOE and the large-animal research by EPRI (RP799-1). This joint study represents the largest effort of its type ever undertaken.

To summarize briefly the small-animal results to date, no effects have been observed in growth, development, metabolic status, fertility, or cardiovascular function after 120-day exposures to 100 kV/m. Subtle effects have been observed in the areas of immunology, behavior, and neurophysiology. The immunological studies showed that although the humoral immune responses (those related to antibody production) were unaffected, exposure to the field decreased the skin response to a foreign protein. The skin response, similar to that seen in a positive tuberculin test, is linked to the cell-mediated immune response. Humoral and cell-mediated immune responses together make up the major components of the immune system. These results may reflect perception of the field at the animals' skin rather than a true effect on the immune response.

Behavioral tests measured the rats' preference to remain in the field or seek a shielded area. The rats avoided 90 kV/m but surprisingly showed a preference for 50 kV/m. These results have not been interpreted. In the neurophysiology studies, ganglia (the major junction points in nerve pathways) from exposed rats displayed a slightly higher excitability than those from controls. Again, the results are open to interpretation.

Effects on large animals

The large-animal studies have only recently begun, and there are no data to report at this time. The major accomplishment has been construction of a facility to house 40 miniature swine (60 kg when fully grown) in a 30-kV/m field and an accompanying control facility to house 20 swine in conditions that are identical except for the electric field. At the completion of the project, researchers hope to have a complete survey of the biological status of the animals originally placed in the field, plus two generations of offspring conceived, born, and raised in the exposure facility.

The research to date has suggested that if ac electric fields induce biological effects, the nervous system and possibly the endocrine system are the likely sites. To explore these possibilities further, EPRI has recently funded work at Tulane University (RP1641) that will involve both live animal exposure and evaluation (in vivo) and exposure of adrenal cortical tissue isolated and placed in a culture medium (in vitro). The adrenal cortex secretes corticosterone; the stimulus for secretion is adrenocorticotropic hormone (ACTH), a circulatory mediator secreted by the central nervous system into the circulation system. The in vitro experiments will show whether the electric field stimulus modulates ACTH-induced corticosteroid secretion. A major objective of the in vivo experiments will be to determine whether electric fields disrupt information transfer on selected nerve tracts. It is still too early to report results.

As part of its expanded field of research, EPRI's Biomedical Studies Program is beginning to tackle important problems in the occupational health area (*EPRI Journal*, May 1979, p. 59). In the high-voltage area, Tabershaw Occupational Medicine Associates, P.A., will begin an epidemiological study of linemen and switchyard workers in January 1980 (RP1644). The aims of the study are to provide information on individuals regularly or frequently exposed to high-level electric fields and to use an electric field dosimeter to provide estimates of exposures from various utility tasks and procedures. In preparation for the full-scale epidemiological study, Equitable Environmental Health, Inc., prepared a feasibility study (EA-1020) that delineated the various approaches available and pointed out their potential pitfalls.

Evaluating the results

Through its high-voltage health studies subprogram, EPRI is gathering the information necessary to evaluate the risks associated with exposures to ac electric fields. Given the variety of life-forms being researched and the broad range of biological parameters being measured, there is small doubt that some field-induced effects will be uncovered. The question about how serious these risks are will continue to be debated in the regulatory and political arenas, and decision makers will have to grapple with the issue of how one discriminates between a biological effect and a biological hazard. EPRI's objective is to collect the most reliable scientific information available.

A future report will discuss planned studies related to the health effects of dc transmission, about which many questions remain unresolved. EPRI hopes to help the industry anticipate the environmental and health impacts of this developing technology. *Project Manager: Robert Kavet*

ANALYZING ATMOSPHERIC PARTICLES

In recent years the utility industry has been paying increasing attention to the particulate matter in the atmosphere. Results of recent research indicate that particles may play a role in human health effects, the formation of acid rain, and visibility degradation. This is of importance to utilities because the burning of coal is one significant source of particles in the atmosphere. Unfortunately, the actual chemical composition of individual particles emitted from stacks is largely unknown. This makes assessment of the environmental effects difficult. However, new techniques for examining particle surfaces by means of energy beams are being applied for detailed characterization of particulate matter.

Typically, atmospheric particles are collected in mass (i.e., thousands of particles are collected on a filter), and chemical analyses are run on this mass. Although it is possible to learn which elements are present in the mass, there is no information on how these elements are combined within individual particles. Knowledge of precise composition (and form) is important for designing meaningful toxicology experiments and for assessing the role of utility activity in creating such phenomena as acid deposition and visibility reduction. This information is also needed for understanding the many complex chemical reactions that take place in the atmosphere.

EPRI's Physical Factors Program carried out a feasibility study at the University of Wisconsin–Milwaukee to evaluate the use of new and sophisticated instrumental techniques for characterizing the shape and chemical composition of individual particles (RP1310).

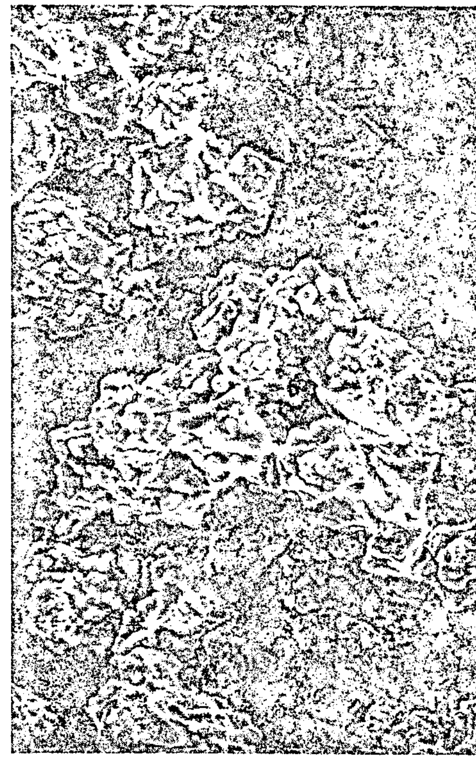
Atomic absorption, infrared spectrometry, spark-arc emission, gas chromatography, X-ray diffraction, and other standard analytic techniques have serious drawbacks for the analysis of microspecies and, in some cases, even for large samples. Generally, these methods examine millions of atoms at a time; consequently, only a bulk analysis is obtained. Certain elements, such as hydrogen, boron, carbon, oxygen, fluorine, nitrogen, phosphorus, and sulfur, are very difficult to detect (especially those in combination with metallic elements) and even harder to quantify.

Irradiating a sample with an electron or ion beam allows investigation of microareas as small as 0.2-μm diameter with depth resolution as small as 0.1 nm (1 angstrom). This means that a region perhaps 2000 atoms wide and only 1 or 2 atoms thick can be chemically identified. Similarly, morphology may be determined for species as small as 50 nm (perhaps a group of only 500 atoms). Thus, energy beam irradiation is ideal for characterization of small (0.1–20 μm) particles and represents the state of the art of microsystem investigation. The analytic equipment capable of this sophistication is referred to by the general term *surface analysis system.* The most useful commercially available technologies are the following.

- Scanning electron microscopy (SEM)
- Transmission electron microscopy (TEM)
- Energy-dispersive X-ray spectrometry (EDX)
- Scanning Auger microscopy (SAM)
- X-ray photoelectron spectroscopy (XPS)
- Secondary ion mass spectrometry (SIMS)
- Ion-scattering spectrometry (ISS)

The appropriate choice or combination of techniques can detect all elements (in many cases, to better than 100 parts per million), reveal information about how these elements are combined (i.e., compound information), and define their location in three dimensions. The analysis is performed on individual small particles, typically of 1–10-μm diameter. Surface area information is initially obtained by irradiation of the particle with an appropriate beam (X-ray, ion, or electron). Depth information is obtained by removal of the surface atoms with an ion beam. Particle size, shape, and topography are obtained by actually forming an electron image, or micrograph, by using the scanning electron microscope. The resultant electron micrograph provides three-dimensional information by detecting electrons emitted from nearly all positions of the particle's surface. Figure 1 is an example of such a micrograph.

Figure 1 Micrograph produced by a scanning electron microscope provides topographic information on particulate matter.



The TEM system is rather ineffective for imaging the topography of unmodified environmental particles. However, this tool is excellent for very thin samples and can provide crystallographic data. Figure 2 illustrates the types of chemical information that can be obtained with the remaining tools (EDX, SAM, XPS, SIMS, and ISS). The figure demonstrates that the surface of the particle is typically quite different from the bulk.

It is not yet clear which chemical or morphological variables govern the environmental effects of particulate matter. For example, it may be only the top layer of pollutant particles that are a health hazard; or it may be the particle size, shape, or topography that is harmful. Thorough character-