HIGH VOLTAGE LINES

HAZARD at a DISTANCE

BY
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AND
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HIGH VOLTAGE TRANSMISSION LINES are highways for energy — paths by which energy moves from the point of creation to the point of consumption. The first overhead transmission line was built in New York City in 1882, and operated at about 110 volts. Presently there are more than 100,000 miles of overhead high voltage (OH-HV) lines in the United States carrying up to 765,000 volts — and, for the future, the utilities industry envisions 1,100,000-volt and 1,500,000-volt OH-HV lines.

In the popular mind, the energy transported by OH-HV lines is visualized as moving through the wires. In fact, however, the energy moves in the direction of the wires, through the space surrounding them.[1] The energy flux (see Figure 1) is composed of both an electric and a magnetic field. The energy is a real, physical — though incorporeal — entity which can be measured, analyzed, and used directly for a variety of purposes. The reality of the electromagnetic energy of OH-HV lines is conveniently demonstrated with an ordinary 40-watt fluorescent bulb. Under a 345,000-volt line, for example, luminous effects occur everywhere within about 100 feet of the line.

Electricity and Biology

Many of the scientists associated with the discovery of electricity and the formulation of its laws were deeply concerned with the significance it held for biology — Helmholtz, Hertz, Faraday, Tesla, Volta, and Galvani, to name a few. Their interest encompassed both the effect of electricity on animals and the role of the electricity which originated within animals.

For reasons now of interest primarily to students of the history of science, the early links forged between electricity and biology were broken. By 1900 the study of electricity had become a free-standing academic discipline; biology, on the other hand, continued to develop quite independently. The search of biologists for answers to problems related to disease, growth, and reproduction, for example, increasingly employed the concepts and framework of solution chemistry. Biologists generally did not incorporate electricity in either their theories or the conduct of their experiments for the

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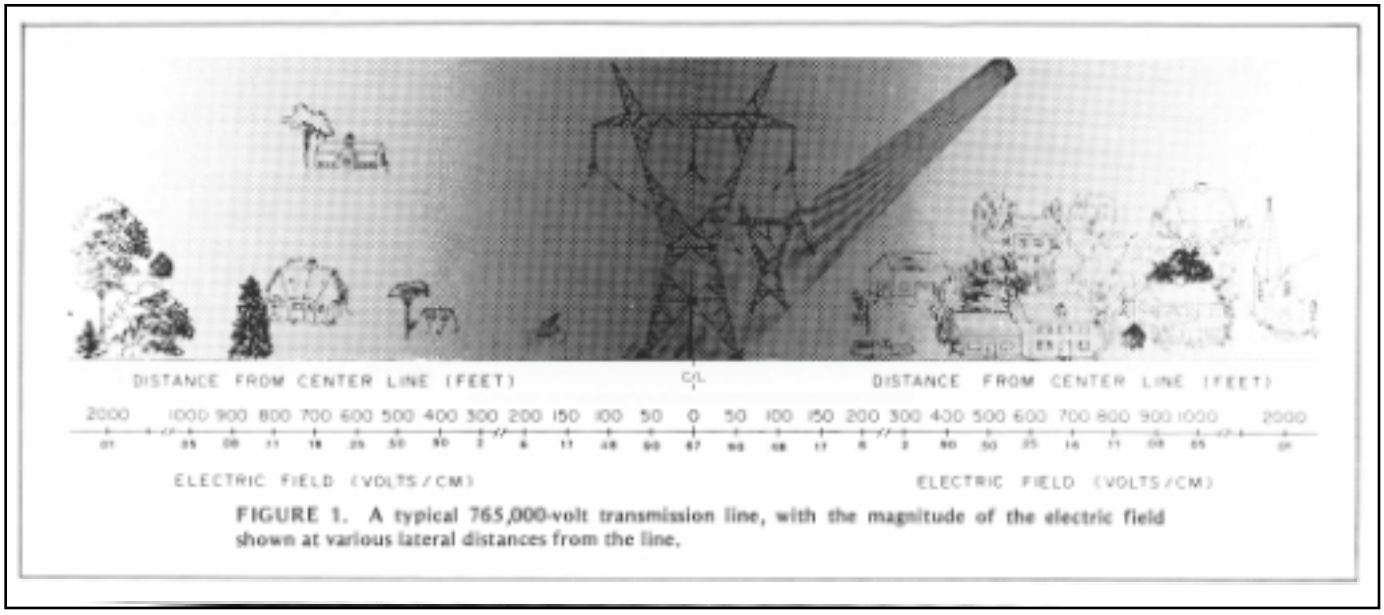


FIGURE 1. A typical 765,000-volt transmission line, with the magnitude of the electric field shown at various lateral distances from the line.

first two-thirds of the twentieth century. During this period the study of electricity evolved into a highly specialized set of disciplines aimed at understanding the interaction of electricity with matter - nonliving matter. OH-HV technology, therefore, matured in the intellectual backwaters of both biology and electrical engineering. Virtually the only knowledge produced by their cross-pollination was the determination of the number of amperes required to stimulate nerves, or to cause a shock, kill, or burn an organism.

It was not until 1967 that two studies, funded by the American Electric Power Company and carried out at Johns Hopkins University, sought to determine whether linemen who had worked on OH-HV lines remained healthy and whether mice, when exposed in the laboratory to the same electrical environment in which the linemen worked, exhibited any untoward physiological effects. Eleven linemen were given physical examinations and no pathologies were observed which the examining physicians felt were occupationally related; two men, however, had low sperm counts. The exposed mice did not appear to be affected; their male progeny, however, which were unexposed and were born of unexposed females, were stunted.

The reception afforded the Johns Hopkins studies clearly reflected the tenor of the times. Both groups called for further work to explore the ramifications of their results, but the studies failed to excite interest or gain the financial support of industry or government. Except for the Johns Hopkins studies, the scientific literature produced in the United States from 1882 until about 1970 contained virtually no data-pro or con, experimental or theoretical -which would permit any objective assessment of the risks of exposure to the energy carried by OH-HV lines.

During this period the utility industry grew from a group of small "mom-and-pop" type companies into today's giant. The regulatory apparatus assembled by the individual states to control the industry focused on insuring that the lines did not produce gross effects, such as shocks and burns. With regard to all other biological effects there prevailed a presumption of innocence. The absence of scientific inquiry into the risks of exposure to the fields of OH-HV lines was routinely accepted as legal evidence tending to prove the nonexistence of such a risk.

Beginning in the mid-1960s scientists began to conduct laboratory experiments dealing with the effects of very minute amounts of electricity on both man and animals. Their individual research aims were diverse: to alter growth patterns, stimulate regeneration, treat tumors, and alter the course of specific diseases, to list only a few. The focus of their research was either therapeutic or purely speculative. It grew out of the scientists' dissatisfaction with the failure of the chemical approach to furnish insights into the way living things work and their desire to utilize the methods and concepts of newly emergent areas of thought, such as solid-state physics and information theory. The results of these experiments, performed by eminent men and women at respected academic institutions, are now widely available. In some instances the electrical environment to which the investigator exposed the biological system under study was similar to that created by an OH-HV transmission line. In these fortuitous instances, depending on the actual experimental conditions, important information was sometimes gained relative to the risks of exposure to the fields of OH-HV lines.

About this time the U.S. Navy proposed the construction of an extremely large antenna to permit communication with submarines. The proposal, called Project Sanguine, envisioned a network of wires in 26 counties in northern Wisconsin. Sanguine's electromagnetic field was to be similar in several respects to that created by OH-HV lines. In particular, Sanguine was intended to operate at essentially the same frequency as OH-HV lines. It would have the same

magnetic field as OH-HV lines, but its electric field was to be about one-millionth that of a typical OH-HV line. Because of the National Environmental Policy Act, a program of experimental studies was initiated by the Navy to permit assessment of Sanguine's environmental impact. As a result, Goodman, at the University of Wisconsin, studied the effect of Sanguine-strength fields on the growth and physiology of the slime mold *Physarum polycephalum*. McCleave, at the University of Maine, studied the ability of fish to perceive such fields. Southern, at Northern Illinois University, studied the effect of Sanguine-strength fields on bird orientation. Noval, of Temple University, studied the ability of such fields to alter the growth rate of rats. Beischer and Gibson, at the Naval Aerospace Medical Research Laboratory, studied the effect of Sanguine-strength fields on human physiology and behavior. Each of these studies, and others, ultimately reported positive effects: the fields caused specific changes in the biological system under study. Sanguine-motivated experiments thus furnished useful information for evaluating OH-HV health risks.

A further significant development in the 1960s was the increasing concern of the government of the Soviet Union for the health of individuals exposed to the fields of OH-HV lines. The Soviet literature contains several hundred studies of the biological consequences of OH-HV type fields.[2] Among them are at least five epidemiological studies involving a total of 727 individuals exposed to the fields of OH-HV lines. In 1970 the Soviet Ministry of Electricity published nationwide rules limiting the duration of exposure.[3] The expansion of ongoing Soviet laboratory research on the effects of OH-HV type fields and the adoption of additional rules were described in 1975. The Soviet reports, and the rules based on them, are of obvious importance in judging the safety and health implications of U.S. OH-HV lines.

Experimental Studies

OH-HV lines operate at a frequency of 60 hertz, which is in the extremely low frequency (ELF) portion of the electromagnetic spectrum (generally limited to frequencies of less than 100 hertz). Thus, any assessment of the impact of OH-HV lines requires a consideration of the literature which describes the biological effects of ELF electric and magnetic fields.[7] This literature indicates that a variety of biological organisms, including man,

The available scientific literature indicates that a variety of biological organisms, including man, are sensitive to both long- and short-term exposure to the extra low frequency electric and magnetic fields produced by high voltage lines.

are sensitive to both long- and short-term exposure to ELF electric and magnetic fields. On the basis of the ELF bioeffects studies described on pages 11 and 12, it must be concluded that both the electric and the magnetic fields of OH-HV lines probably can cause biological effects in subjects exposed to them. The question therefore becomes one of whether OH-HV lines will cause (or are causing) such effects. The strength of the field employed in each of the experiments cited was such that we know that it will occur somewhere in the vicinity of OH-HV lines. If a particular field strength causes a certain biological effect in the laboratory, then the same field strength will cause the same effect where it occurs along a right-of-way, if the same biological system is exposed under the same conditions. That much is obvious. The actual biological systems that will be exposed to the fields of OH-HV lines include people. The exposed group will consist of the old, the young; the sick, the healthy; men, women, children—a completely uncontrolled set of subjects. Therefore, both the particular biological systems that will be exposed and the conditions of such exposure will differ from the systems and conditions prevailing in the laboratory. Moreover, in not a single instance do we know the basic cellular or molecular process, the actual mechanism, by which the applied fields affected the text organism. Thus, the knowledge indispensable for extrapolating scientific results does not exist. For this reason it is not possible to predict the specific biological consequences that will occur in specific subjects exposed to specific intensities of the fields surrounding OH-HV lines.

Such a conclusion is hardly surprising because, with minor exceptions, the ELF bioeffects studies were performed for reasons other than the evaluation of the safety of electric transmission lines. It is therefore not to be expected that answers to the myriad of specific questions that can be asked will be deducible from this literature. In spite of the obvious inability to predict specific effects in specific sub-groups of the exposed population, the implications of the literature are ominous. In each report described in the table on page 12, ELF fields interacted with and influenced the physiology or behavior of a biological system. In each case a presently unknown mechanism of interaction caused results in the laboratory which could be caused along a right-of-way as a consequence of exposure to the fields of OH-HV lines. In view of the number and diversity of the reported experiments, and bearing in mind the relatively short exposure times normally employed in laboratory experimentation as compared with the long-term exposure to which people living along rights-of-way would be subjected, it seems likely that biological effects will occur in some subjects exposed to the fields of OH-HV lines.

It takes only brief reflection to realize that every biological effect induced in people by OH-HV lines is potentially hazardous and should be avoided. Medically, such effects are unacceptable because they are not induced in the best interests of the patient. Legally, such effects could be held to constitute the tort of battery because they result from contact with a foreign substance which the average person may reasonably regard as offensive. Ethically, even if the

effect were not assumed to be hazardous, it would still involve an enormous, utility-operated, involuntary human experimentation program in which the utility would modify its transmission line depending on its view of the severity of the effects produced.

Industry-Sponsored Research

Almost all of the research linking health risks with exposure to the fields of of OH-HV lines has come from projects not funded or controlled by the utility industry. The first industry project, the 1967 Johns Hopkins studies which found reduced sperm counts in linemen and stunted growth in male progeny of exposed mice, was not followed up. Instead the industry funded a study, ultimately known as RP-98, involving the exposure of cells, dogs, and baboons. When the Electric Power Research Institute (EPRI) was founded in 1972, it assumed responsibility for almost all industry research on OH-HV lines; in particular, it began to support RP-98. In early 1974 the RP-98 scientists ascertained the threshold at which OH-HV type fields were 100 percent lethal to isolated cells.[6] The report, however, was not accepted or published by EPRI.

The following year, after the RP-98 group described the ability of brief exposure to OH-HV type fields to alter the physiology of dogs and the apparent ability of baboons to detect the presence of such fields and thereby modify their behavior,' EPRI terminated RP-98. No final report was ever published even though the project cost more than onehalf million dollars, and EPRI's present research program does not acknowledge that there ever was an RP-98.8

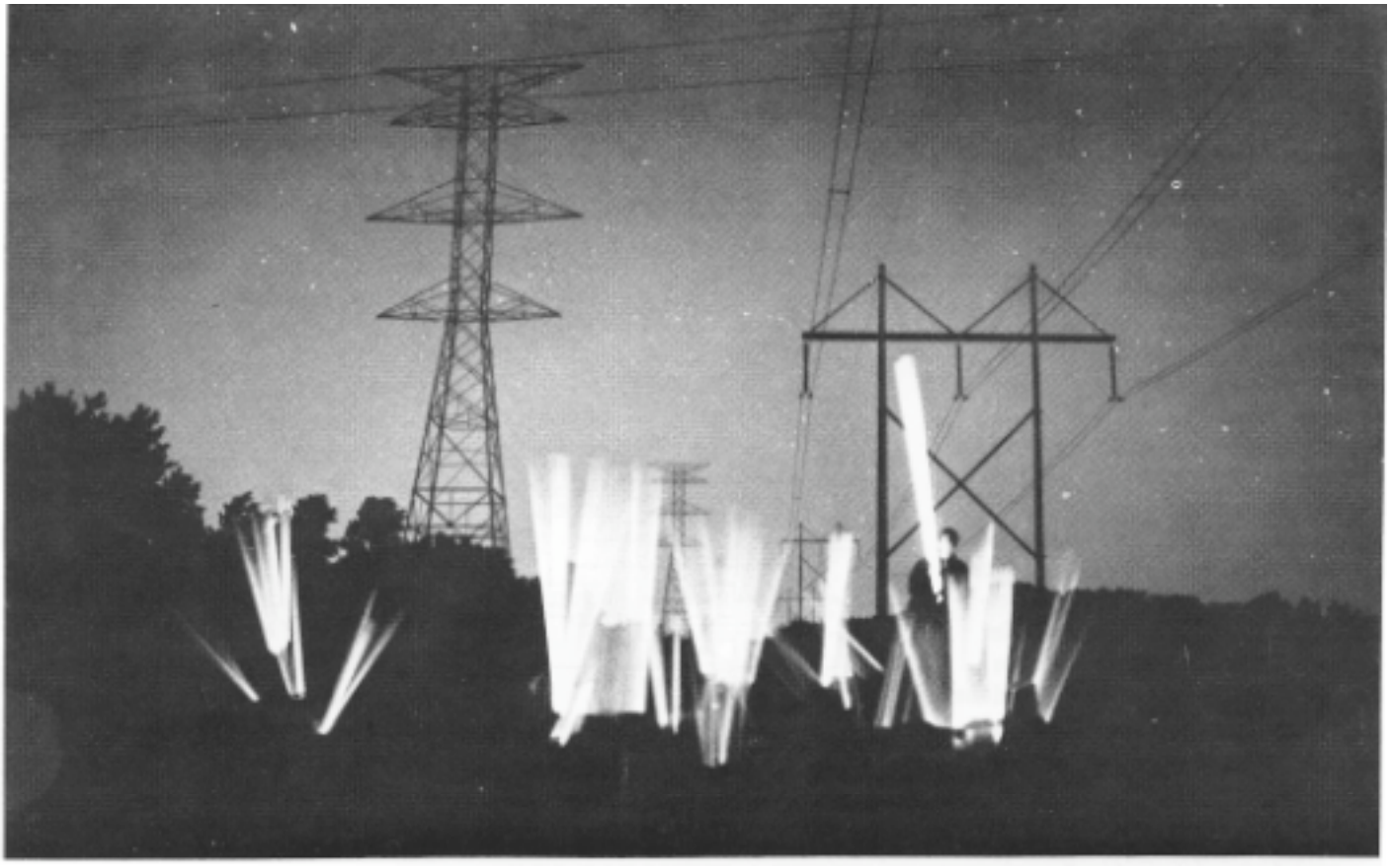
In 1975 work began on EPRI's RP-129, a study jointly conducted by Westinghouse and Penn State with the aim of exploring the effects of OH-HV fields on a wide variety of biological systems, including both plants and animals.' In the initial experiments positive effects were observed,[10] whereupon RP-129 was redesigned to concentrate on the effects of ozone on plants, a relatively trivial biological effect quite unrelated to the health risks experienced by people exposed to the fields of OH-HV lines.[11]

In 1976 EPRI funded a project to study the possibility of conducting a study of the health status of individuals who worked on OH-HV lines.12 EPRI has refused to disclose the details or results of the study[13] or to reveal whether the actual study is being, or has been, performed.

In March 1976 EPRI funded RP-799 at Batelle Laboratories to study the effect of OH-HV type fields on reproduction in pigs.[14] The experimental protocol calls for research which cannot possibly answer any reasonable question concerning the health and safety of OH-HV lines. Even so, the project has been underway for more than two years, at a cost exceeding one million dollars, and no data have been released.

In 1975 and 1976 several reports appeared describing adverse effects of OH-HV lines on bees. Shortly thereafter, a

Luminous effects can be produced everywhere within about 100 feet of a 345,000-volt line. Here fluorescent tubes are being lit by the electric field under power lines in Binghamton, New York.



David Tinney/Binghamton Evening Press

corporation, Bioconcern Incorporated, was formed which received an EPRI grant to review the existing literature dealing with the effects of fields on bees. Bioconcern concluded that existing studies lacked scientific merit,15 whereupon it received a second EPRI contract (RP-934) to conduct such studies. Apparent adverse effects in bees have recently been reported.

In addition to the Battelle and Bioconcern studies, EPRI also carries out other activities in the ELF bioeffects area which are subject to only partial disclosure or are totally secret. These include translation of the foreign literature and trips to the Soviet Union by EPRI personnel to visit with Soviet utility engineers. EPRI acknowledges the fact of the translations but treats the translated material as proprietary and therefore not subject to general release. The purpose of EPRI's trips to the Soviet Union is said to be to ascertain whether "someday a uniform answer to the problem of electric fields will be available in both countries."[17] It is also likely that EPRI is supporting secret ELF bioeffects research at both private research institutes and at the facilities of individual companies which manufacture equipment for utility companies.

The Department of Energy (DOE), and in particular the Division of Electric Energy Systems, is unabashedly pro-industry. In 1976 DOE became concerned about whether OH-HV fields cause biological effects. It contracted with Battelle for a series of studies on rodents and flies at a cost of about 2 million dollars.

The DOE-Battelle studies raise many problems, the most serious being that they have no truly useful purpose. At the time the rodent studies began, for instance, about forty groups of investigators had reported biological changes in animals due to ELF fields. The proposition that ELF fields can cause biological effects was therefore already firmly established and the DOE-Battelle studies could not fruitfully have its testing as their purpose. The studies are being done at very high-field intensities and under extremely unusual experimental conditions; they do not simulate the experimental conditions utilized in any previous study. Consequently, regardless of the results, the DOE-Battelle studies are inherently incapable of confirming or conflicting with any other investigation. Also, since the study is so heavily funded, it seems virtually certain that it will never be repeated. A third purpose one might envision, since DOE is responsible for the design of the study and the evaluation of the results as they concern human health hazards, is the elaboration of data upon which DOE might base decisions about the risk to the public due to exposure to the OH-HV lines. The studies, however, are developing information concerning biological systems exposed under highly aberrant experimental conditions. Thus, the results can have virtually no direct public health significance. More such DOE-designed and supported studies at other research institutes are in the offing.

Figure 2 illustrates the highly in-bred relationships which exist in the ELF area in the United States. The Navy, DOE, and EPRI furnish almost all the money spent on ELF bioeffects work. The relationship between high voltage transmission lines and the Navy's Project Sanguine has led to cooperation between the utilities and the Navy. The chief civilian contractor utilized by the Navy, the IIT Research Institute (IITRI) has taken the position that there are no health or environmental effects which result from exposure to the fields of OH-HV lines.18 IITRI furnishes no actual research; it functions almost exclusively in a public relations capacity wherein it produces reports and primers to inform the public[19] and guide the federal government. DOE and EPRI have an admittedly intimate relationship-money, personnel, and the designs for research projects flow freely between them. Presently, the greatest part of the publicly committed ELF research funds are being spent at Battelle, the cost being about evenly split between EPRI and DOE. Various individual power companies, the source of EPRI's money, employ the Rochester Group (Morton Miller, a botanist; Solomon Michaelson, a veterinarian; and Edwin Carstensen, a physicist) to testify that OH-HV lines are safe. The Group, thus far, has appeared in four states and two Canadian provinces representing eight different power companies. The Rochester Group is supported by research funds from the Navy, the Rochester Gas and Electric Corporation, and DOE. Additionally, it is an advisor and consultant to EPRI, IITRI, and the Navy. Although the Group has not published any ELF animal research,[21] they, together with Bioconcern's investigator, are the only active scientists recognized by EPRI as experts in the ELF bioeffects area.

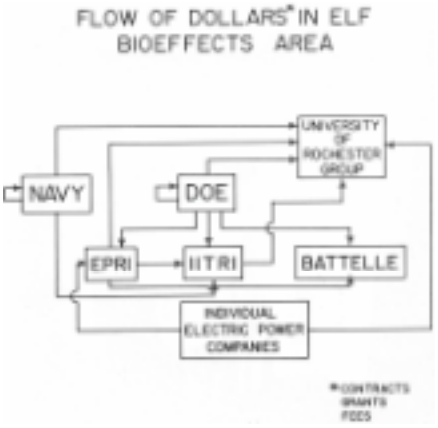


FIGURE 2. The indicated pathways account for the bulk of the funds spent on extra-low-frequency bioeffects research.

Other Problems

The ELF bioeffects literature clearly indicates the existence of health risks; on the other hand, the cost of retrofitting existing lines will be great. It would be helpful if we could at least ascertain the dimensions of the problem posed by OH-HV lines. There are, however, health-related aspects of such lines which are potentially more troublesome than the problem of direct exposure to the ELF fields, although they cannot presently be adequately assessed. The most important of these are synergism, induced current, and global weather modification.

Synergism

The energy carried by OH-HV lines is composed of electric and magnetic fields. An individual exposed to the energy is exposed to both fields simultaneously. Although ELF electric fields and ELF magnetic fields are each known to cause biological effects, the effects produced by the simultaneous application of both fields have not been studied

experimentally. The biological response to simultaneous application may be equal to the summation of the effects produced by each field separately, or it may be considerably greater. The latter response is called synergism and is a condition in which one agent becomes more potent in the presence of another agent. Thus, the actual situation which exists near OH-HV lines—simultaneous application of both fields—has not been studied. There is a possibility of a synergistic interaction between the fields in subjects exposed to OH-HV lines—and also between the energy flux, the fields taken together, and other agents present in the environment. In a recent survey, for example, we found a suggestive relationship between the incidence of cancer and living near a communications and power complex consisting of two television antennas, five FM communications antennas, thirteen microwave relay antennas, and an extensive power transmission and distribution system.[23] There is presently a complete absence of inquiry into the question of synergistic interactions resulting from OH-HV lines, which seems inconsistent with the present broad-scale pattern of public exposure.

Induced Current

Consider a person standing beside an automobile near an OH-HV line. The line's fields impinge on them, thereby inducing an electric charge on both. When the subject touches the car, an electric current flows between them, through their mutual point of contact. The current from a typical OH-HV line is 100 microamperes at 150 feet or 1 microampere at 650 feet.[24] If the object being touched were ten times larger—say a tractor-trailer—then the induced current would be correspondingly greater at each distance. Conversely, if the object touched were smaller—an umbrella or a baby carriage—the induced current at each distance would be proportionately smaller. For large objects near or under OH-HV lines, the currents are quite painful. For smaller objects—or for larger objects located further away—the induced currents that flow through the point of contact are below the threshold of pain or sensation. Sub-threshold currents have traditionally been assumed to be biologically innocuous.[25] This assumption, however, has been proved false.

Beginning in the late 1960s, there has appeared a large number of scientific studies describing growth-stimulating characteristics of very weak electric currents. The most frequently studied tissue in this regard has been bone.[26] The reports, which are exceedingly diverse, typically involve the application of 1 to 10 microamperes for one to three weeks to a particular skeletal location. The absolute *upper* limit for such experiments is about 100 microamperes, since the chronic administration of higher levels of current leads to gross tissue destruction.[27] Currents below 1 microampere have been utilized to heal specific bone defects in human beings. Because weak-current biological effects have now been established, the problem of OH-HV line-induced current must find at least part of its resolution in the study of human activities which take place within about 2,000 feet of OH-HV lines, a study which must include a determination of what objects are contacted, how often, and for how long.

Helliwell Phenomenon

Our discussion so far has centered on the biological consequences of exposure to the energy flux of OH-HV lines that moves outside but along the wires. During its transit some of this energy is lost through radiation. Unlike the energy flux, the radiated energy travels radially outward from the transmission line into space in the same manner as an ordinary broadcast signal. In November 1975 alterations in the earth's magnetosphere due to radiation from OH-HV lines were reported.[29] The magnetosphere is universally recognized as an important influence on life on earth. *Physics Today* reported:

> A team from Stanford Radioscience Laboratories, headed by Robert Helliwell, has also found evidence that these power-line emissions are amplified within the magnetosphere and cause the precipitation

In a multi-generation study in which mice were continuously exposed to a 60-hertz electric field, Marino found that both male and female mice weighed less than unexposed mice. The second-generation female mice at the left were exposed to the ELF field; those at the right were not.

> of electrons from it.... Together with the results of earlier experiments, the new findings indicate that this "rain" of electrons affects the ionosphere, which is at the bottom of the magnetosphere, in a number of ways, including the production of ion pairs, and bremsstrahlung X-rays.... What possible benefits and environmental impact do these results point to?[30]

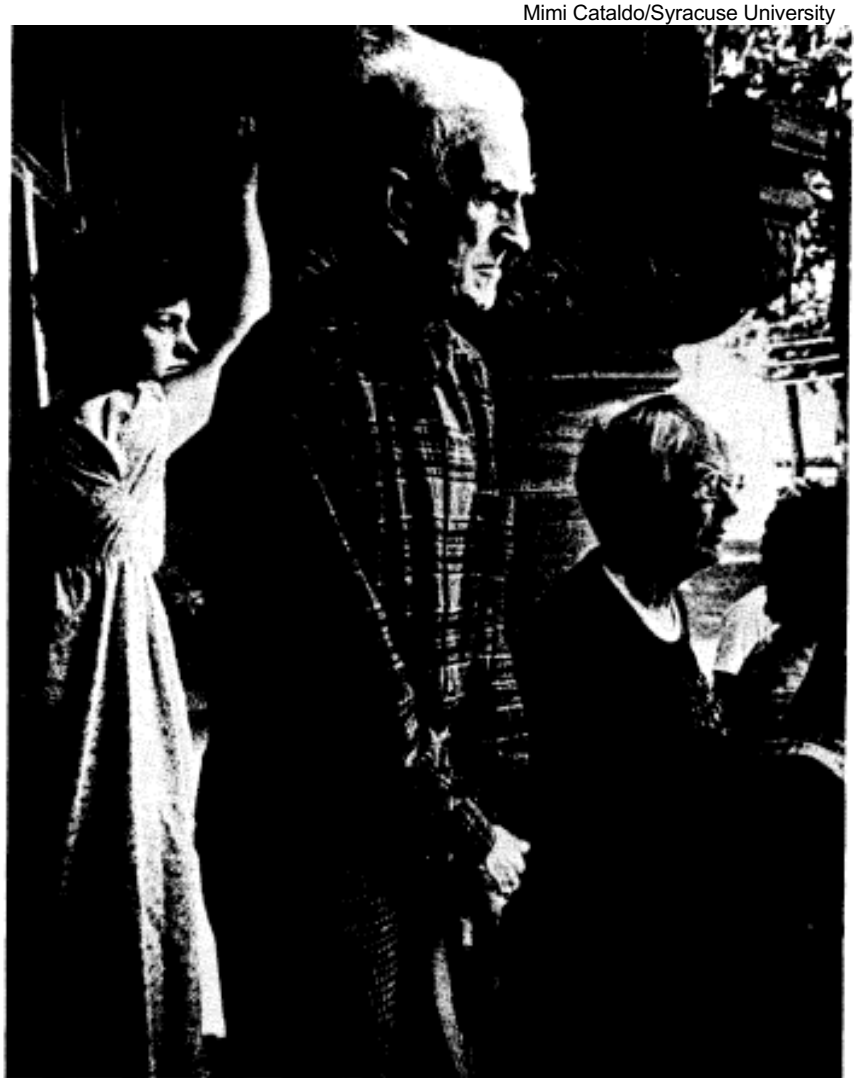
The plain answer is that no one knows.[31] The discovery of the Helliwell phenomenon, and its subsequent confirmation, raises two important questions: what changes in the magnetosphere are due specifically to radiation from OH-HV lines and what is the biological significance of such changes? We know, for instance, that the X-rays produced by the electron rain ultimately result in ultraviolet light which reaches the earth's surface. In addition, changes in the electron rain might have the effect of altering global weather patterns. There are thus a number of speculative but highly important aspects of the Helliwell phenomenon caused by OH-HV lines—and by ELF communications systems like Sanguine which are *designed* to radiate. The basic physical processes unequivocally exist: this is guaranteed by the existence of the Helliwell phenomenon. However, the question of the extent and biological significance of the OH-HV radiations has not yet been addressed.

The New York Hearing

For more than four years the Public Service Commission (PSC) of New York has held hearings on the health and safety of OH-HV lines. In its final decision the PSC recognized the existence of a health risk. It widened the right-of-way for new lines to a minimum of 350 feet and a maximum of 1,200 feet.[32] The PSC also created an Administrative Research Council (ARC), composed of independent scientists free of any ties whatsoever to the utilities, with authority to fund research on ELF bioeffects by other independent scientists. The level of support envisioned for the ARC is such that the New York effort will be by far the largest and most detailed inquiry in the United States into the health risks posed by OH-HV lines.

The most fundamental conflict in the PSC hearings was between the advocates of the "biophysical" and "biological" methods of analysis. The former approach applies the principles of physics to biological systems in order to determine how, in theory, electromagnetic fields can produce biological effects. A determination is then made as to whether OH-HV fields can theoretically produce such effects. In this approach, theory is the touchstone; experimental results not explained by theory are viewed as presumptive aberrations. In the biological approach, the experimental results are basic, and one judges a theory solely in terms of its ability to explain observed relationships. Inasmuch as no theory presently predicts ELF bioeffects, the distinction between the two approaches is of obvious significance. The adoption of the biophysical approach is equivalent to accepting the presumption that OH-HV lines are safe because they cannot cause any effects whatsoever. On the other hand, adoption of the biological approach necessitates a consideration of the individual ELF bioeffects reports. The PSC rejected the biophysical approach as a basis for determining public policy. It said: "The recent history of science is just too burdened by surprising discoveries of adverse effects for a government agency

Mimi Cataldo/Syracuse University



Upstate New York residents stand on the steps of the courthouse in Canton to listen to legal proceedings arising out of actions they had taken to prevent the power company from using their land for a 765,000-volt line.

to make its decision principally in reliance on this sort of evidence."

The second significant aspect of the hearings was the PSC's resolution of the conflict between its staff and the utility companies concerning the issue of the quality of the ELF experimental literature. The staff concluded that "OH-HV lines would probably cause biological effects in humans exposed to them," basing its conclusion on about twenty ELF studies which it considered to be the strongest and most reliable.[33] The utilities launched an allout attack against the ELF investigators.[34] The PSC did not rule directly on the competence of any particular investigator, but it held that the ELF reports taken together "contained unrefuted inferences of possible risks that we cannot responsibly ignore." With the creation of the ARC, the PSC manifested its intention to generate its own data for assessing the safety of OH-HV lines.

A further dispute between the PSC's staff and the utilities focused on the distinction between an effect and a hazard. The utilities argued that an effect induced in the bodies of subjects exposed to the fields of OH-HV lines must not be presumed to be hazardous. The staff argued that common sense suggested that such effects must be presumed to be hazardous. The PSC held that it was "charged with protecting the public and [had] no alternative but to presume that a biological effect is hazardous until proven otherwise."

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The need to protect the American public from involuntary exposure to power frequency fields is now clear. Numerous experiments have demonstrated that such fields are biologically active at existing environmental levels; given these findings, the burden of establishing the safety of each radiation source must be borne by its proponents. The focus of the controversy will now shift to other spheres. State and ultimately federal-regulators must now seek to determine the extent of the hazard presented by high voltage transmission lines and must try to devise means for weighing the amount of protection against the costs that will have to be incurred.

NOTES

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9. J. W. Bankokse and G. McKee, **Ecological Influence of Electric Fields**, RP-129, Electric Power Research Institute, Interim Report, May 1975.

10. J. W. Bankoske, G. McKee, and H. B. Graves, **Ecological Influence of Electric Fields**, RP-129, Electric Power Research Institute, Interim Report 2, September 1976.

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12. Anonymous, "Perspective on 765,000-volt Transmission: An Industry Report," Electric Perspectives, March 1976, pp. 13-17.

13. Letter from H. A. Kornberg, Environmental Assessment Department, to R. A. Simpson, Staff Counsel, Public Service Commission of New York, November 2, 1976.

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A wooden model of a high voltage tower is burned at a rally held near Potsdam, New York, to protest power company plans to build new lines.

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Experimental Results of
ELF Bioeffects Research

Solov'ev demonstrated that several hours exposure to high *electric fields* was fatal to mice and fruit flies. Bees also exhibited strongly altered behavior leading directly to lethal consequences, according to Warnke. The rate of cell division in the liver and the cornea of mice tripled following application of an ELF electric field for four hours (Mamomtov).

ELF fields also affect various forms of animal behavior. Spittka found a decrease in the response rate of trained rats at high fields, and Gavalas observed an increase in the response rate of monkeys at low fields. McCleave showed that eels and salmon were able to perceive extremely small fields. Friend found that amoebae exhibited changes in shape and orientation within a few minutes of the application of ELF electric fields. Sazonova found that 300 volts/ cm decreased the ability of rabbits to do work.

Five laboratory studies treat the interaction of ELF electric fields and human subjects; in each instance alterations in human reaction time were reported (Johansson, Hauf, Hamer, Konig, and Persinger). Two animal studies reported direct effects of brief electric field exposure on the central nervous system: Gann found that blood pressure and heart rate were significantly different in exposed dogs; Lott found that the field altered the electroencephalograms of rats. Investigations by Gann, Southern, Larkin, and Williams indicated that very weak ELF fields could affect the orientational ability of birds.

Behavior was the most frequently studied biological variable in these short-term electric-field experiments. However, in long-term experiments, growth, or some other physiological aspect of a developing biological system, was studied more often.

Knickerbocker found that the male progeny of field-exposed male mice had reduced body weights. In a multigeneration study, Marino found that both male and female mice were smaller. Aberrant growth responses following chronic exposure to electric fields have also been reported in rats, flatworms, and slime mold. McElhaney found that rats developed bone tumors, and Goodman observed delays in rate of division and intra-cellular movement in slime mold. When flatworms were subjected to the field, the normal growth pattern was altered (Marsh). Rats exposed to an ELF electric field for one month exhibited a variety of effects including depressed body weight, depressed water consumption, and altered blood proteins. The results indicated that exposure to the field produced a physiological stress response. Noval independently performed similar experiments, at much lower field strengths, and reached the same conclusion. Mathewson performed similar experiments; his data reveal a number of biological effects supporting the stress hypothesis, including changes in blood glucose, hemoglobin, proteins, lipids, and triglycerides.

Wever, using both shielded and unshielded underground bunkers, found that the absence of the earth's natural electromagnetic fields lengthened the period of the human body temperature rhythm. He also found that the normal synchronization between different rhythms was destroyed when the subjects were confined to a shielded bunker in which the natural fields of the earth were not present. He further found that the presence of an artificial ELF electric field reversed both effects. This phenomenon has also been reported by Altman and Lang.

Soviet investigators have conducted a number of medical and physiological surveys of people exposed to electric fields emanating from the Soviet electrical power system. Physical examinations of high voltage switchyard workers revealed that 41 of 45 subjects studied presented some neurological or cardiovascular disorder during or shortly after field exposure (instability of pulse and blood pressure, tremors, slowed heartbeat). A physiological survey of 54 workers showed that the electric field produced functional changes in the autonomic nervous system which were related to the duration of exposure. Medical surveys carried out at sixteen high voltage substations, involving a total of 286 people, revealed that the field had adverse effects on the nervous and cardiovascular systems. When 23 men were exposed to OH-HV type fields while various central nervous system and cardiovascular system indices were measured, the results showed that fields stronger than 50 volts/cm have an adverse effect. A clinical study of personnel at 330,000-volt substations revealed a variety of harmful effects of field exposure. In recent laboratory studies rats were exposed for up to four months in an effort to assess the human health hazard posed by OH-HV lines. Unusual motor activity, reduction of blood cholinesterase, and an increase in urinary corticoids were observed at fields of 10-50 volts/cm. Dystrophy was seen in a variety of tissues in a degree proportional to the intensity of the applied field and the duration of exposure.

ELF *magnetic fields* have been shown to have behavioral effects. Friedman found that a field of 3 gauss significantly affected reaction time. The effect of ELF magnetic fields on human cognitive functions was examined by Gibson. Eleven men were confined to a testing facility for seven days, during which the magnetic field was turned on for 24 hours (the subjects were unaware of the actual exposure period). Their performance in two tests-one of short-term memory and one of the ability to perform addition-was altered by their exposure to the field. Smith found that activity of mice increased when an ELF magnetic field was applied; Persinger found that rats displayed increased activity after removal from such a field. In two studies by Bassett, an ELF magnetic field accelerated the healing of bone fractures and caused bone growth in patients suffering from a bone disease.

Summary of ELF Research

Investigator	Institution	Animal Studied	Field Applied (v/cm)	Frequency (Hertz)	Duration	Observation	D* (Feet)	Right-Of-Way
Gann	Johns Hopkins	cells	6000	60	7 days	cell death	near wire	176
Solov'ev	USSR	mice, insects	5000	50	several hours	death	near wire	200
Knickerbocker	Johns Hopkins	mice	1600	60	10 months	altered growth	near wire	302
Blanchi	Turin University	mice, rats	1000	50	1000 hours	altered physiology	near wire	354
Watson	University of Wales	chick tissue	1000	1	9 days	altered growth	near wire	354
Spittka	University of Berlin	rats	500	50	several minutes	altered behavior	near wire	446
Milmer	University of Berlin	rats	500	50	10 days	altered behavior	near wire	446
Bamkoske	Westinghouse-Penn State	chicks	400	60	1 -8 weeks	altered behavior	near wire	500
Sazanova	Leningrad University	rabbits	300	50	18 hours	altered behavior	0	550
Friedman	VA Hospital -Syracuse	humans	3 gauss	0.2	several hours	altered behavior	0	550
Mamontov	Moscow Medical Institute	mice	200	50	4 hours	altered growth	0	604
Gann	Johns Hopkins	dogs	150	60	5 hours	altered physiology	0	668
Marino	VA Hospital -Syracuse	rats	150	60	1 month	altered growth	0	668
Warnke	University of Saarbrucken	bees	110	50	several days	altered behavior	0	735
Marino	VA Hospital -Syracuse	mice	100	60	6 months	altered growth	0	760
Bassett	Columbia University	dogs	1 $\mu a/cm^2$	65	28 days	altered growth	0	760
Bassett	Columbia University	humans	1 $\mu a/cm^2$	56	3-6 months	altered growth	0	760
McElhaney	West Virginia University	rats	70	30	23 days	altered growth	82	853
Beischer	Naval Aerospace Research Lab	humans	1 gauss	45	1 day	altered physiology	0	1000
Gibson	Naval Aerospace Research Lab	humans	1 gauss	45	1 day	altered physiology	0	1000
Giarola	Texas A&M University	chicks	35	45	28 days	altered growth	111	1082
Altman	University of Saarbrucken	mice	35	10	3 days	altered behavior	111	1082
Lang	University of Saarbrucken	mice	35	10	56 days	altered behavior	111	1082
Kruger	Texas A&M University	chickens	16	60	4 months	altered physiology	150	1410
Friend	Naval Research Institute	amoebas	10	1-100	10 minutes	altered physiology	177	1673
Moos	University of Illinois	mice	10	60	10-150 days	altered behavior	177	1673
Marsh	University of Iowa	flatworms	3.1	60	5 days	altered growth	256	2538
Altman	University of Saarbrucken	guinea pigs	2.4	10	13 days	altered physiology	282	2821
Reisen	IIT Research Institute	cells	1.55	60	40 minutes	altered physiology	328	3411
Mathewson	Radiobiology Research Institute	rats	0.5	45	1 month	altered physiology	460	>1 mile
Lott	North Texas State University	rats	0.4	640	90 minutes	altered physiology	517	>1 mile
Bawin	UCLA	brain tissue	0.1	1.75	20 minutes	altered physiology	836	>1 mile
Hamer	UCLA	humans	0.04	2-12	several minutes	altered behavior	1164	>1 mile
Gavalas	UCLA	monkeys	0.035	7-75	several minutes	altered behavior	1230	>1 mile
Wever	Max Plank Institute	humans	0.025	10	8 weeks	altered physiology	1394	>1 mile
Durfee	University of Rhode Island	cells	0.01	60	3 days	altered growth	2000	>1 mile
Konig	Technical University-Munich	humans	0.01	3-10	several minutes	altered behavior	2000	>1 mile
Goodman	University of Wisconsin	slime mould	0.007*	45-75	600 days	altered growth	2363	>1 mile
Noval	Temple University	rats	0.005	45	1 month	altered growth	2722	>1 mile
Southern	Northern Illinois University	birds	0.002**	45-76	2 minutes	altered behavior	4100	>1 mile
Graue	Bowling Green State University	birds	0.0007**	76	several minutes	altered behavior	>1 mile	>1 mile
Larkin	Rockefeller University	birds	0.0007**	72-80	several minutes	altered behavior	>1 mile	>1 mile
Williams	Swarthmore College	birds	0.0007**	72-80	several minutes	altered behavior	>1 mile	>1 mile
Anonymous	Naval Research Unit No. 4	humans	0.0007**	45-76	not specified	altered physiology	>1 mile	>1 mile
McCleave	University of Maine	fish	0.0007	60-75	several minutes	altered physiology	>1 mile	>1 mile

*** D is the distance from a typical 765,000 volt transmission line at which the field decreases to the value employed in the corresponding experiment. The last column utilizes a safety factor of 100—it lists the width of the right-of-way necessary to prevent entry into an area in which the field exceeds 1/100 of the value employed in the corresponding experiment.**

****Magnetic field also present.**