

ANNALS OF RADIATION

THE HAZARDS OF ELECTROMAGNETIC FIELDS

I-POWER LINES

IN the spring of 1974, a woman named Nancy Wertheimer began to spend a day or two each week driving through residential neighborhoods in Denver, stopping once in a while in front of a house or an apartment building to have a look around. Each time she got back into her car, she jotted down a few facts in a small notebook: whether the house or the apartment building was one story or more, whether it was constructed of wood or brick, and how close it was to a school, a factory, or a major thoroughfare. If the residents of the neighborhoods had taken notice of her, they would have observed a tall, sombre-looking woman of forty-seven, with blue eyes, high cheekbones, and graying, curly hair, who was driving a ten-year-old Dodge Dart station wagon. Wertheimer was an epidemiologist who was just resuming her professional career after a six-year hiatus, and the list of addresses she was consulting, which she had obtained from the Colorado Department of Vital Statistics, contained the home address at birth of every child in the four-county Greater Denver area who had died of leukemia between 1950 and 1969, along with birth addresses of a matched list of children without cancer.

Wertheimer was born in New Haven, Connecticut, and graduated from the University of Michigan in 1948 with a B.S. degree in psychology and biology. In 1954, she received a Ph.D. in experimental psychology from Harvard and Radcliffe, and a year later she moved, with her husband, a psychologist, and their children, to Boulder, Colorado. She spent the next decade there raising her family and working part time on a study of schizophrenia. In 1968, she was awarded a fellowship by the Department of Health, Education, and Welfare to investigate a possible relationship between childhood leukemia and maternal age and season of birth, but by then she had been divorced for

several years, and she turned the fellowship down in order to spend more time with her children, who were teenagers. When she finally got around to the leukemia study, it was with the idea that the disease might be linked to some kind of environmental or infectious factor. For this reason, she was on the lookout for clustering among the addresses of its victims as she began driving through the residential sections of Denver. She had no funding for the study, so she was working on her own time and paying expenses out of her own pocket. "I was doing what epidemiologists sometimes do at the start of an exploratory investigation," she said recently. "I was looking for some kind of pattern."

As things turned out, Wertheimer did not come across any unusual clusters of childhood-leukemia victims during her preliminary explorations. She did, however, notice something that seemed a bit out of the ordinary. "It was on my third or fourth trip," she recalls. "I had stopped at one of the

birth addresses—an old frame house on the edge of the warehouse district in downtown Denver—and I walked into an alley behind it, which ran between the back yards of two rows of similar houses. It was a mixed neighborhood—black, white, and Mexican—and many of the houses were run down. Like most back-yard alleys in the Denver area, this one was paved, so that trucks could get through to pick up garbage and trash, and it contained a number of poles strung with electrical wires and telephone lines. When I looked up I noticed an electrical transformer on a power pole behind the house I had stopped to examine. The transformer was black and cylindrical, and it was attached to the pole above a crossbar that supported several electrical wires, and when I saw it I said to myself, 'Hey, haven't I been seeing a lot of these things lately?'"

Wertheimer did not initially attach any great importance to this observation. A short while later, however, she remembered seeing a magazine article



"Lunch Thursday at one? Looks good to me."

that was accompanied by a photograph of a boy holding a pair of fluorescent lamp tubes that lit up because he was standing in the electric field beneath a high-voltage power line. The article had suggested that the emanations from power lines might be hazardous, and, with this in mind, Wertheimer got in touch with an official of the Public Service Company of Colorado and obtained the addresses of the dozen or so power substations in the Greater Denver area. At these installations, she learned, voltages as high as two hundred and thirty thousand volts (two hundred and thirty kilovolts), which were carried by high-voltage power lines from generating plants, were being stepped down by large transformers to thirteen thousand volts, producing correspondingly greater amounts of current for distribution along primary wires to neighborhoods within the city. (Electric current—a flow of charged particles which always produces an electromagnetic field—can be likened to water flowing in a pipe, and voltage can be thought of as the pressure that pushes current through a circuit.) Wertheimer proceeded to map the sites of the substations in relation to the birth addresses of childhood-leukemia victims and their matched controls, her idea being that if electric fields were somehow associated with the disease the link might show up in the vicinity of high-voltage wires. The map showed only a faint correlation between the two, however, and she realized that she would have to test her initial observations in a more direct manner.

Up to this point, Wertheimer had surveyed about fifty of some hundred and fifty dwellings on her list of birth addresses, so the next thing she did was revisit those dwellings, taking particular note of the presence and the

proximity of pole-mounted transformers. These transformers step down the thirteen thousand volts carried by the primary wires to the two-hundred-and-forty- and one-hundred-and-twenty-volt levels that are required to operate household electrical equipment and appliances. Current is then carried locally, for relatively short distances from the transformers, at these lower, household voltages, in wires known as secondaries.

When Wertheimer began rechecking the birth addresses, she was not expecting to find anything unusual, but during the next few weeks an association between transformers and childhood leukemia kept leaping out at her. "It was puzzling," she recalls. "The more I went around, the more the correlation cropped up. It simply wouldn't go away. Moreover, about the time I finished rechecking the old addresses and started visiting new ones

I began to observe an additional baffling pattern. Houses in which young leukemia victims had lived were not just those closest to pole-mounted transformers but, with unusual frequency, were also the houses next door—in other words, the second house from the transformer. The leukemia rate dropped off sharply at the third house and was low in all the subsequent houses on the line. I didn't know what to make of this, of course, but I was tremendously interested in it, even though I was sure it would turn out to be a fluke."

BY autumn, Wertheimer was discussing her mysterious findings with a physicist friend named Ed Leeper, who lives in the foothills of the Rocky Mountains, just west of Boulder. He, too, was puzzled by her observations, but since he knew that the various parts of an electrical-distribution system carry uniform voltages, regardless of their distance from transformers, he reasoned that the phenomenon she was encountering could not be associated with the alternating electric field. (Current for industrial and household use is known as alternating current, because it is generated and supplied at a frequency of sixty hertz—formerly called cycles per second. That means that it flows back and forth, first in one direction and then in the other, sixty times a second.) Leeper therefore suggested that if there was in fact a correlation it might be with the magnetic field arising from the flow of current in the transformer, although he pointed out that such fields would drop off so rapidly that they should be negligible at the house. A correlation with magnetic fields would be especially interesting, however, **because**, unlike electric fields, which



"In the official language of the State of Florida, buzz off."

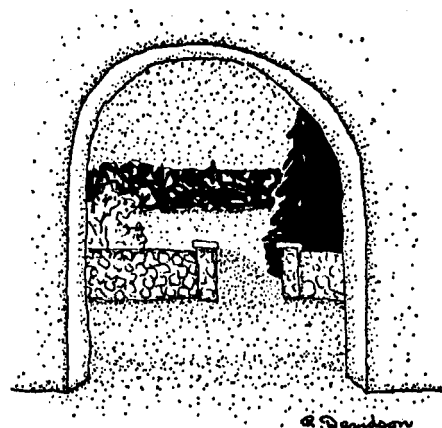
can easily be shielded by conducting materials, magnetic fields-invisible lines of force that interact with magnets and certain metals-readily penetrate almost anything that happens to stand in their way, including the human body.

In December of 1974, Leeper fashioned a crude gaussmeter (a gauss is a unit of measure for magnetic-field strength), using a coil employed by television repairmen to demagnetize TV sets and the audio amplifier and speaker of an old walkie-talkie, and presented it to Wertheimer as a Christmas gift. The contrivance provided an estimate of the strength of an alternating magnetic field, and also transformed it into a sound, which could be heard on the speaker as a hum. After learning to operate the gaussmeter, Wertheimer drove to a middle-class neighborhood on the northwest side of Boulder one morning in early January of 1975 and parked her car near a pole-mounted transformer at the entrance to a back-yard alley. "The poles in the alley were placed at the corner of every other lot, and they were strung in a manner that was typical of the power-distribution system in the Greater Denver area," she recalls. "At the top of each pole was a thin, primary wire carrying seventy-six hundred volts. Below that was a crossbar strung with several two-hundred-and-forty-volt secondaries. The thin primary had branched off from an array of thicker primaries that came directly from a substation, and it had already supplied power to dozens of such transformers, which, in turn, provided reduced voltages to secondary wires that fed current into hundreds of homes.

"When I got out of my car, I walked to the base of the transformer pole at the alley entrance and switched on Ed's meter. It gave off a loud hum that indicated the presence of a fairly strong magnetic field. I was prepared for that, of course, but when I started walking up the alley, away from the transformer pole, I found that, contrary to what Ed and I had expected, the hum did not begin to diminish until I got past the next pole, at the far corner of the second house lot, from which several wires known as service drops carried current into nearby dwellings. Those were the first service drops that reduced the current load fed into the secondary distribution line by the transformer. As I continued walking

past the second pole, a strange thing happened: the hum indicating the presence of the magnetic field dropped off sharply. For a while, I couldn't understand the significance of this. Then it dawned on me that the point where the magnetic field fell off coincided with the pronounced decrease in the leukemia rate I had previously observed at that point, I talked with Ed Leeper and we realized that we had been mistaken in assuming that the increased incidence of leukemia I had seen at the two houses nearest the transformer was associated with closeness to the transformers. The association was really between those two houses and closeness to the first span of the secondary wire -the part that ran past the two houses on its way from the transformer pole to the second pole, from which the initial service drops were made. This part of the secondary wire was carrying current for all the dozen or more homes that were being served by the secondary, and that is why it was giving off the strong magnetic field I had heard as a loud hum. Once we had made that connection-the link between the first-span secondary, with its relatively high current and strong magnetic field, and the two houses where so many leukemia victims had lived-I began to think I might be onto something."

During the rest of 1975, Wertheimer spent a great deal of time making measurements of the magnetic fields surrounding first-span secondaries elsewhere in Greater Denver and correlating those measurements with the birth addresses of children who had died of leukemia. The results of her preliminary analyses indicated that childhood-leukemia victims had lived disproportionately often in dwellings that had first-span secondaries running past them. Toward the end of the year,



Leeper built her a more sophisticated meter that could accurately measure sixty-hertz magnetic fields in terms of gauss, and when she began using this instrument to assess the strength of the magnetic fields surrounding other types of wires she found that certain kinds of primary wires gave off relatively strong magnetic fields-as great as, or greater than, those of the secondaries she had been measuring. As a result, she predicted that if the magnetic fields produced by high current in secondary distribution lines were associated with excess leukemia among children, then high current in the primary wires would produce the same association.

Since Wertheimer had formed this hypothesis on the basis of the birth addresses of childhood-leukemia victims, sound epidemiological method dictated that it would be necessary for her to test the prediction with new data. For this reason, she went back to the Department of Vital Statistics and got the addresses at birth, and also the addresses shortly before diagnosis, of all children in the Greater Denver area who had died of cancer of any kind between 1950 and 1973. Three hundred and forty-four such cases were included in the study. She also selected a matched-control population of three hundred and forty-four children, each of whom had a birthdate closely following that of a child who had died of cancer. She then devised a wiring-configuration code that would allow her to classify each dwelling that had been lived in by a case or a control in terms of its proximity to high-current or low-current wiring.

High-current homes included those situated less than a hundred and thirty feet from three-phase, large-gauge primary wires or from an array of six or more small-gauge primary wires; homes that were less than sixty-five feet from an array of three to five small-gauge primary wires; and homes less than fifty feet from first-span secondary wires, which were defined as secondary wires that issued directly from a transformer and had not yet lost any current through service drops. First-span wires serving no more than two single-family homes were considered to be in the low-current category, as were all other configurations of the distribution wires. Dwellings that were situated beyond the end pole of a secondary line, and thus had no distribu-

tion wires running past them, were considered the extreme example of low-current houses.

During 1976, Wertheimer visited the birth and diagnosis addresses of each of the cancer cases, the birth address of each of the controls, and the addresses at which control children had been living at the time their matched cases had been found to have cancer. Next, she drew a diagram describing the situation, the size, the type, and the proximity of the electrical wires and transformers she had observed in the vicinity of each of these homes. Once that was done, she analyzed the data and found that her prediction had held up: children who had lived in homes near high-current electrical wires had died of cancer at twice the rate seen in children living in homes near low-current wiring. The association was strongest among those children who had spent their entire lives in a high-current home. Particularly disturbing was the fact that of six children in the study population who had lived near high-current wires coming directly from power substations, all were cancer victims.

To satisfy herself that her findings were not the result of some artifact accidentally associated with high-current wiring, Wertheimer spent 1977 and the early part of 1978—she was still working on her own time and with her own money—analyzing and reanalyzing the data in relation to such possible co-factors as population density and air pollution and noise from traffic congestion. When she could discover nothing to explain her findings other than the association with the magnetic field resulting from high current, she and Leeper wrote a paper describing their study and its outcome, and submitted it to the *American Journal of Epidemiology*, which is published by the Johns Hopkins University School of Hygiene and Public Health, in Baltimore, and is considered one of the foremost epidemiological journals in the world. After peer review, the paper was accepted, and it appeared in the *Journal's* March, 1979, issue, under the title “Electrical Wiring Configurations and Childhood Cancer.” The first paragraph said:

Electrical power came into use many years before environmental impact studies were common, and today our domestic power lines are taken for granted and generally assumed to be harmless. However, this assumption has never been ade-

quately tested. Low-level harmful effects could be missed, yet they might be important for the population as a whole, since electric lines are so ubiquitous. In 1976-1977, we did a field study in the greater Denver area which suggested that, in fact, the homes of children who developed cancer were found unduly often near electric lines carrying high currents.

Wertheimer and Leeper went on to say that current flow (and, by extension, the magnetic fields induced by current flow) was always greatest in electrical wires leading from a distribution substation or a pole-mounted transformer. “At these points, the voltage has been stepped down and ‘transformed’ into current,” they wrote, adding, “It was particularly homes close to these transforming points that were over-represented among our cancer cases.” After acknowledging that magnetic fields are usually cancelled in ordinary wiring, where the return current tends to balance the supply current, they pointed out that such cancellation is imperfect in the vicinity of many dwellings, “because the wires are often separated in space and, more importantly, because some of the return current does not flow through the wires at all, but returns instead through the ground, and particularly through the plumbing system to which most urban electrical systems are grounded at each house.” They explained that the ground current flows not only in street plumbing but also through the pipes of houses, and thus produces magnetic fields in these houses which appeared to be related to the wiring configuration near each house.

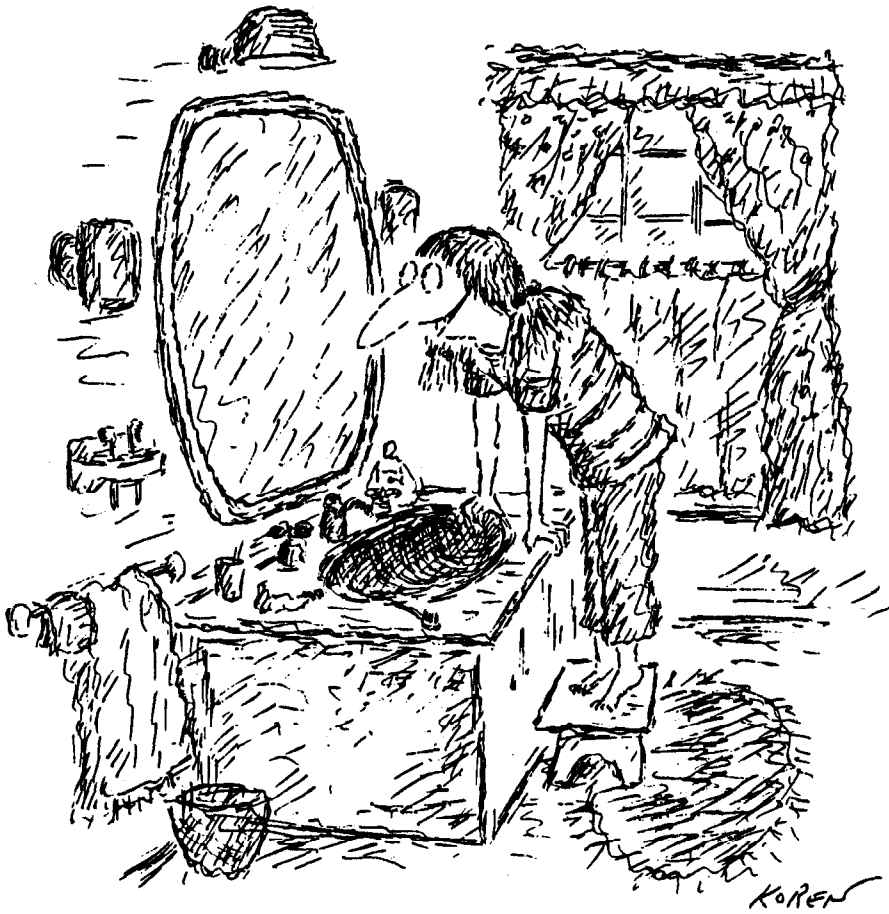
Aware that measurements had been made showing that household appliances could produce strong sixty-hertz magnetic fields (an electric drill, for example, creates a field of thirteen gauss at a distance of one centimetre), Wertheimer and Leeper warned that such measurements were not a valid



index of exposure, because they had been made very close to the appliance, and because appliance-generated fields usually fall off rapidly with distance. They also noted that magnetic-field exposure to the whole body from normal use of household appliances rarely exceeds two milligauss (a milligauss is one-thousandth of a gauss) for any extended period, while “ambient fields in a house due to nearby distribution wires or plumbing may sometimes reach those levels, or more, for hours or days at a time.” This fact led them to conclude that if magnetic-field exposure was responsible for the increased incidence of childhood cancer which they had observed, the duration of continuous exposure above some minimum threshold might be more important than the strength of the exposure per se. To support the hypothesis that magnetic fields were associated with cancer, Wertheimer and Leeper said that, upon analyzing a 1950 United States Public Health Service report correlating cause of death with occupation in men between the ages of twenty and sixty-five, they had found that workers who were frequently exposed to alternating-current magnetic fields—among those workers were power-station operators, telephone linemen, power linemen, subway and elevated-railway motormen, electricians, and welders—had developed cancer at a significantly higher rate than the population as a whole.

Wertheimer and Leeper went on to suggest that alternating magnetic fields might indirectly affect the development of cancer by hindering the ability of the body’s immune system to fight cancer. They also suggested that it is conceivable that the immune system might utilize electric potentials occurring at cell surfaces, and they advanced the disturbing theory that when the human body was subjected to an electromagnetic background different from the level that had existed during man’s evolution the operation of the immune system might be altered. They emphasized that, whatever the reason for the correlation they had observed, the risk of cancer for children living in homes near high-current wiring was rarely increased by a factor of more than two or three.

“At the time our paper was published, I felt terribly ambivalent about our findings,” Wertheimer recalls. “Part of the trouble stemmed from a



"Looking good! Feeling great! And soon to be famous!"

deep concern that we might worry people unduly. I hated the idea of making people feel bad about their homes, especially if there was little or nothing they could do to correct the situation, and for this reason I was reluctant to speak to the press about our findings, or to make any special effort to publicize them. I should also say that the very idea that the kind of electrical wiring one could find in the streets of almost any town or city in America might be hazardous to health seemed well, unbelievable. Additionally incredible was the fact that the cancer increase we had observed was associated with such weak sixty-hertz magnetic fields. The static magnetic field that is present at all times on earth was several hundred times as strong as those fields, and the magnetic fields that were described in the available medical literature as having essentially no biological effects whatsoever were thousands of times as strong. On the other hand, one out of every four or five families in our study lived in a dwelling that we had categorized as a high-current home, and that raised the

possibility that, if the risk were real, alternating magnetic fields from electrical wiring could pose a very large public-health hazard across the nation, as well as elsewhere in the world. Such a possibility obviously had to be investigated in greater detail, and for this reason I fully expected that the medical and scientific community would jump at the chance to study it."

WERTHEIMER'S expectation notwithstanding, the medical and scientific community not only failed to deem her findings worthy of further consideration but dismissed them out of hand, on the ground that there was no experimental evidence to support the hypothesis that the magnetic fields from ordinary high-current wires could cause cancer. Encouraged by such orthodoxy, the electric-utilities industry tried to discredit her work, and, as a result, more than eight years passed before the association she had discovered between high-current wires and cancer was corroborated in the United States. That belated confirmation might have been even further

delayed if it had not been for a courageous stand taken, back in 1973, by Dr. Robert O. Becker, an orthopedic surgeon and research scientist at the Veterans Administration Hospital in Syracuse, New York, who had become convinced that the electromagnetic fields emanating from power lines could pose a serious threat to human health.

Becker is a bespectacled, blue-eyed, slightly built man who was born in River Edge, New Jersey, in 1923, and attended Gettysburg College, in Gettysburg, Pennsylvania, where he majored in biology. He got his medical degree from the New York University School of Medicine, in New York City, and subsequently became an orthopedic surgeon. In 1956, he was made chief of orthopedic surgery at the V.A. Hospital in Syracuse, and there he soon became interested in the regenerative aspects of bone healing.

In the early nineteen-sixties, Becker conducted experiments with salamanders—animals whose remarkable regenerative powers include the ability to grow new limbs, a new tail, new jaws, and new eye lenses, as well as portions of their brain and heart—which showed that the regenerative process was initiated by electric current associated with the nervous system. After hypothesizing that the direction of flow and the magnitude of this current might also control brain activity and consciousness, he induced deep anesthesia in a salamander by placing it in a strong magnetic field. This work stimulated new interest in the biological effects of magnetic fields, because, although the power of the lodestone to attract metal had been revered by the ancients—they believed that magnetism held the secret of life—the biological effects of magnetism had remained largely outside the realm of accepted scientific inquiry in modern times.

Throughout the sixties, Becker continued to experiment with electricity and living organisms, and contributed to the discovery that bone fractures in human beings heal in the same electrically controlled manner that governs the regeneration of limbs in the salamander. Some of his most significant work in this period consisted of exploring the influence exerted upon the activity of the brain by external magnetic forces, including those of the magnetic field of the earth. In 1963, he and Howard Friedman, a psychologist at

the V.A. Hospital in Syracuse, showed that there was a relationship between the dates of admission of patients to the psychiatric services of hospitals and the occurrence of solar magnetic storms. In 1965, they exposed human volunteers to pulsed magnetic fields of similar frequency and considerably greater strength than those associated with magnetic storms, and found that doing so significantly slowed the volunteers' ability to react to the appearance of a light by pressing and releasing a telegraph key. A year earlier, however, a Soviet investigator named Yuri Alexandrei Kholodov had reported that exposure to even stronger magnetic fields caused areas of cell death in the brains of rabbits, and when Becker and Friedman learned of this they discontinued their experiments with human beings and advised other researchers to do the same. Then, in replicating Kholodov's experiment, they discovered that a magnetic field produced stress in rabbits which activated a preexisting but quiescent brain disease, and that this disease produced the lesions Kholodov had observed.

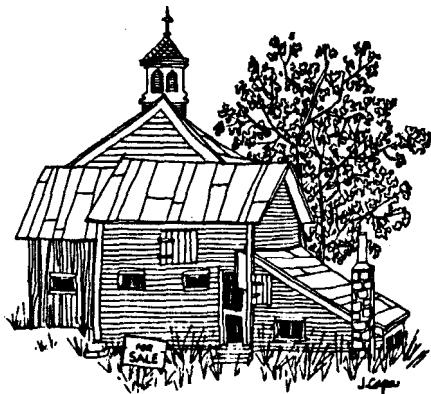
The fact that magnetic fields could induce stress worried Becker, because of an earlier finding, by the endocrinologist Hans Selye, that prolonged stress can adversely affect the immune system. (It had already occurred to Becker during his experiments with salamanders that if electric current could govern benign growth it might also play a role in the development of malignant growth.) He became even more worried when Friedman exposed chimpanzees to pulsed magnetic fields of much lower strength than those employed by Kholodov, and found that the animals excreted elevated levels of adrenal-cortical hormones—a well-recognized sign of stress. He was particularly concerned by the fact that the biologically active magnetic fields that he and Friedman had used in their experiments lay within the extra-low-frequency or **ELF**, range of one to a hundred hertz—the principal frequency range of the earth's magnetic field, to which the human body had been tuned during its entire evolutionary period—because the results therefore suggested that man-made **ELF** fields, such as those created by the sixty-hertz electrical-distribution system, whose emanations permeate the modern environment, might have serious consequences for human health.

In the summer of 1972, Becker warned a meeting of the Institute of Electrical and Electronic Engineers about "the continuous exposure of the entire North American population to an electromagnetic environment in which is present the possibility of inducing currents or voltages comparable with those now known to exist in biological control systems." At the same time, he called urgently for an early program to study the problem of human exposure to electromagnetic energy. A year later, he was invited to serve on a seven-man advisory committee that was being convened by the Navy's Bureau of Medicine and Surgery to review a research program the Navy had instituted on the biological and ecological effects of **ELF** radiation. The committee met at the Naval Medical Research Institute, in Washington, DC., on December 6th and 7th of 1973, and Becker's subsequent revelation of its deliberations marked a dramatic turning point in his career and initiated a bitter controversy over the safety of sixty-hertz electric and magnetic fields that continues to this day.

NAVY officials had become interested in **ELF** radiation back in 1958, when they learned that radio waves oscillating just above the sixty-hertz range could penetrate seawater sufficiently to provide communication with deeply submerged submarines. Subsequently, they learned that a portion of the earth's interior could be used as a launching pad to propagate **ELF** signals, and in 1968 the Navy and the GTE Sylvania Corporation, of Lynn, Massachusetts, built an **ELF** test facility near Clam Lake, Wisconsin, by burying twenty-eight miles of insulated cable in the ground above the low-conductivity granite bedrock of the Chequamegon National Forest. Soon

thereafter, the Navy proposed to construct a twenty-two-thousand-five-hundred-square-mile antenna system—to be called Project Sanguine—by burying six thousand miles of cable elsewhere in northern Wisconsin and in the Upper Peninsula of Michigan. The idea was to form a giant grid so that electric current generated by transmitters would pass through the antenna cables and flow deep into the earth, along the bedrock, and back up into the cables, creating a global **ELF** radio field extending up to the ionosphere—a region of electrons and electrically charged particles in the upper atmosphere, between forty and two hundred and fifty miles above the earth—which would reflect a portion of the **ELF** field into the world's seas and oceans.

Environmental groups mounted opposition to Project Sanguine soon after the Clam Lake facility was constructed, because some people living near it reported that they were receiving electric shocks whenever they turned on their water faucets, and because ordinary wire fences suddenly became electrically charged. At that time, the environmentalists claimed that the alternating magnetic fields generated by the **ELF** antennas could produce voltages in nearby electrical conductors, such as power lines, telephone lines, and wire fences, and that those voltages posed a potential health hazard to the several hundred thousand people who would be living within the boundaries of the Sanguine system. From the beginning, the Navy claimed that no harmful biological effects were caused by **ELF** electric and magnetic fields, and that the environmental effects of Project Sanguine, which was designed to operate at a frequency of about seventy-six hertz, would be no different from the effects caused by sixty-hertz power lines. As for any magnetic-field hazard that might exist, Navy officials sidestepped this by pointing out in a 1972 environmental-impact statement for Project Sanguine that many common household appliances—among them hair dryers, can openers, and food mixers—give off strong magnetic fields. They made no mention of the fact that these fields fall off rapidly within a few inches of the appliances, and thus could not be compared with the magnetic fields that would be given off by the large antennas of Sanguine or, indeed, by power lines. Such omissions notwithstanding,



studies financed by the Navy's own **ELF** biological-research program had begun to cast doubt upon claims that Sanguine was safe, and it was for this reason that the advisory committee in which Becker had been invited to serve was formed.

Becker has said that the only thing **Sanguine** about Project Sanguine was its name. In any event, he and the other members of the committee found little to be cheerful about when they met to evaluate the results of the Navy's **ELF** research. To begin with, they learned that an experiment performed at the Naval Aerospace Medical Research Laboratory, in Pensacola, Florida, had produced significant increases in serum triglycerides—a warning of possible stress—in the blood of nine out of ten human volunteers who had



been exposed to a low-intensity magnetic field. They also learned that abnormally high triglyceride levels had been found in six out of eight workers at the Navy's Sanguine test facility at Clam Lake. There were other disturbing findings. In a study conducted at the Brain Research Institute of the University of California at Los Angeles, monkeys exposed to **ELF** fields showed a decrease in the ability to perform lever-pressing tasks—an indication that **ELF** might have adverse behavioral effects—and in a study conducted by scientists at the Naval Air Development Center, in Johnsville, Pennsylvania, rats exposed to weak **ELF** fields did not gain weight as readily as unexposed control animals. Still other experiments showed that long-term exposure to **ELF** retarded the growth of chicken embryos, and that alternating-current magnetic fields produced disorientation in the chicks of ring-billed gulls—a result suggesting that magnetic fields could affect bird migration.

Not surprisingly, the committee reacted strongly to these findings. Its members recommended as “urgent and absolutely necessary” that further studies be made of the effects of the planned Sanguine **ELF** fields on triglyceride levels in human beings and animals, and that extensive investigations be conducted of the influence of **ELF** on the central nervous system, on cells and chicken eggs, on the growth rate of rats, and on bird migration and orientation. The committee advised the Navy that “since the immune system is

such an important and critical defense mechanism, it behooves Project Sanguine to investigate the operational efficiency of immune mechanisms during and after exposure to **ELF** electric and magnetic fields.” Most important of all from the public-health point of view, the committee voted unanimously to go on record as recommending that the Electromagnetic Radiation Management Advisory Council (**ERMAC**)—a nine-member panel that had been established in 1968 by the President's Office of Telecommunications Policy to advise the President on the biological hazards of microwave and radio-frequency radiation—“be apprised of the positive findings evaluated by this Committee and their possible significance, should they be validated by further studies, to the large population at risk in the United States who are exposed to 60 hz fields from power lines and other 60 hz sources.”

The Navy, for its part, compiled the findings and recommendations of the advisory committee in a thirty-one-page report and effectively suppressed them, marking the report “For Official Use Only” and limiting its distribution to members of the committee and other people who had participated in the two-day meeting. As a result, the warning that the committee had voted to send to **ERMAC** concerning the safety of the nation's sixty-hertz electrical-distribution system went undelivered. Indeed, the whole matter might have been swept under the rug if Becker had not happened to read a copy of the *Lowville Journal & Republican* upon his return from Washington. He and his wife had recently bought land for a vacation-and-retirement home in Lowville, a small town on the western slope of the Adirondacks, about sixty miles northeast of Syracuse, and the *Journal & Republican* carried a notice about a proposal of the Power Authority of the State of New York (**PASNY**) to build several 765-kilovolt power lines in the state, in order to import electricity from a giant hydroelectric-power generating station that was under construction at James Bay, in northern Quebec. According to the notice, the first of the proposed 765-kilovolt lines would run from Massena, a city on the St. Lawrence River at the Canadian border, to the town of Marcy, ten miles northwest of Utica—a total distance

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of roughly a hundred and fifty miles—and would pass through the outskirts of Lowville.

Three days later, Becker wrote a letter to Henry Diamond, the state Commissioner of Environmental Conservation, with a copy to Joseph Swidler, the chairman of the New York State Public Service Commission (P.S.C.). After giving a brief description of Project Sanguine, Becker told the officials that its antennas would transmit electromagnetic radiation at frequencies similar to those of sixty-hertz power lines, and at electric- and magnetic-field strengths “Lower than those that would be present along the proposed 765 kV line and for some distance out from the line.” He then informed them that the Navy’s advisory committee had concluded that the civilian population might be at risk from exposure to the stronger electromagnetic fields emanating from sixty-hertz power lines. He urged that permission for the construction of the Massena-to-Marcy line be withheld until the Project Sanguine experiments were completed and an evaluation of the true extent of the hazard could be made. By way of furnishing corroboration, he advised the two men to ask the Navy’s Bureau of Medicine and Surgery for information regarding the advisory committee’s findings and recommendations.

AT the time Becker wrote his letter, public hearings for PASNY’S proposed Massena-to-Marcy line were under way in Massena, and within a few months hearings began near Rochester for a sixty-six-mile, 765-kilovolt transmission line that the Niagara Mohawk Power Corporation and the Rochester Gas & Electric Corporation wanted to build from Rochester to Oswego. Experts for PASNY and the two power companies testified that the electromagnetic fields of the proposed transmission lines would present no biological hazard, but when a citizens’ group raised the health issue at the Rochester hearing the Public Service Commission felt obliged to look into the matter. In July of 1974, a twenty-seven-year-old P.S.C. lawyer named Robert Simpson visited Becker at his office at the V.A. Hospital in Syracuse, and listened intently as Becker described in detail the adverse biological effects of ELF fields which had been turned up by the Navy’s research pro-



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gram on Sanguine. (The P.S.C. had requested a copy of the advisory committee's report on the program, but the request had been denied by the Navy's Bureau of Medicine and Surgery, on the ground that the information it contained was classified.) Also present at the meeting in Becker's office was Andrew Marino, a thirty-three-year-old biophysicist with a law degree, who had been working in Becker's laboratory for nearly ten years. Marino told Simpson about a study he had recently conducted in which rats exposed to sixty-hertz electric fields gained less weight and drank less water than unexposed control animals. Rats in a related experiment showed altered levels of blood proteins and enzymes.

At the conclusion of the meeting, Simpson asked Becker and Marino if they would be willing to come to the Rochester hearing and testify about the biological effects of ELF radiation. The two men not only agreed to do so but decided to testify without remuneration. The P.S.C. procedure required them to submit written reports and then undergo cross-examination, and in October they sent their reports to Simpson, and he forwarded them to Niagara Mohawk and Rochester Gas & Electric. In addition to describing

the results of his rat experiments, Marino's report cited eight studies published in the medical literature which showed that ELF radiation could cause biological effects on human beings or animals. For his part, Becker wrote that ELF fields were biological stressors, and that as a physician he would have to assume that their effects could be harmful. The suggestion by scientists that electromagnetic energy from power lines might be hazardous to human health appeared to take Niagara Mohawk and Rochester Gas & Electric by surprise, and the two companies requested that the Rochester hearing be postponed for a year, so that they could call additional expert witnesses and produce new testimony.

By the time the P.S.C. hearings resumed, in late 1975, state officials had decided that the application of Niagara Mohawk and Rochester Gas & Electric for the 765-kilovolt transmission line from Rochester to Oswego would be joined with PASNY's application for the Massena-to-Marcy line, and that the testimony of Becker and Marino would be presented in behalf of the P.S.C.'s staff, who are specifically charged by law with the responsibility of representing the interests of the public. In February of 1976, however, the

P.&C. bowed to pressure from Governor Hugh Carey and authorized the construction of the Massena-to-Marcy line. (The Governor had sent a bill to the New York State Legislature that, if it passed, would have ordered the P.S.C. to approve PASNY's power-line project.) Thus, the issues that remained to be decided were whether the width of the right-of-way of the Massena-to-Marcy line, which PASNY and the utilities wanted to be two hundred and fifty feet, would be expanded for health and safety considerations, and whether Niagara Mohawk and Rochester Gas & Electric's application to build any more 765-kilovolt

lines in the state would be approved.

During the yearlong postponement, Becker and Marino had combed the medical literature and found more than twenty additional studies that described biological effects in human beings and animals of exposure to ELF electromagnetic fields. Meanwhile, Marino had conducted repeated experiments in which he exposed rats to sixty-hertz electric fields whose strength was almost identical to that which could be expected at ground level beneath a 765-kilovolt line, and had found changes in the animals' body weight and blood chemistry. He had then subjected three generations of mice to the same fields, exposing the animals from birth through maturity and mating, and had found that the second and third generations of exposed animals were severely stunted in comparison with unexposed control animals. He had also found a significantly increased mortality rate in the exposed mice.

The hearings dragged on for nearly two and a half years, producing more than fourteen thousand pages of testimony by thirty-one witnesses. The case against the transmission lines rested chiefly on Marino's experiments and on thirty-two other studies showing that ELF fields could cause biologi-

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cal effects, such as disturbances in human biorhythms, slowed reaction time in monkeys, disorientation in birds, and increased heartbeat rate in fish. Equally important was the testimony of Becker, the only medical doctor to appear as a witness for either side. He stated that the weight of this evidence suggested that biological effects would occur in human beings who were subjected to long-term exposure to electromagnetic fields from the lines.

To counter their testimony, PAsNY and the two utility companies retained the services of several experts. Chief among them was Herman P. Schwan, a professor of electrical engineering and physical medicine at the University of Pennsylvania's Moore School of Electrical Engineering, in Philadelphia. Schwan, who had previously been a professor at the Kaiser Wilhelm Institute of Biophysics, in Frankfurt, Germany, had come to the United States in 1947 under the auspices of Operation Paperclip—a government program designed to make the talents of German scientists available to the nation's defense effort. He had soon begun to conduct research on the biological effects of microwave radiation, and in 1953 he proposed to the Navy, which was seeking to develop an exposure standard for personnel who were operating high-power radar, that a safe level of exposure for human beings could be set at ten milliwatts of power per square centimetre of body surface. (The power, or intensity, of microwaves, radio waves, and other high-frequency non-ionizing electromagnetic radiation is customarily expressed in terms of power density, which is the amount of radiation that flows each second through a square measure of space.) Schwan arrived at the ten-milliwatt level on theoretical grounds, basing it largely on the fact that energy from the metabolism of food is normally dissipated by the surface of a human body at rest at the rate of about five milliwatts per square centimetre. His assumption was that another five milliwatts per square centimetre could be applied by external forces, such as microwave irradiation, without causing a significant rise in the body's temperature. Although the ten-milliwatt standard was a thousand times the level of occupational microwave exposure then considered safe by the Soviet Union, it was adopted as a tentative standard in the late nineteen-fifties

by the Army, the Navy, the Air Force, the Bell Telephone Laboratories, and the General Electric Company. By 1966, it was also generally accepted as a guideline for occupational exposure by the electronics industry and by most state and federal health agencies.

When Schwan testified at the P.S.C. hearings, he said that the power levels of the electromagnetic fields emanating from the proposed 765-kilovolt transmission line could not interact with the body's cells to produce internal fields capable of heating tissue or exciting nerves, and therefore the risk to human health and safety appeared to be virtually nonexistent. He also said that no non-thermal or other low-level effects of ELF fields had been proved, and he dismissed the thirty-two studies of ELF effects cited by Becker and Marino as either irrelevant or inconclusive or incompetently conducted.

Another witness who testified for PASNY and the utility companies at the P.S.C. hearings was Professor Sol M. Michaelson, a doctor of veterinary medicine at the Department of Radiation Biology and Biophysics of the University of Rochester's School of Medicine and Dentistry. During the nineteen-sixties, Michaelson, whose research was financed largely by the Navy, had conducted numerous experiments on the heating effects of microwaves by exposing dogs and other test animals to radiation of sufficiently high intensity to produce deep burns and death within a few hours. Although he had performed few, if any, experiments at levels below ten milliwatts per square centimetre, he claimed to have confirmed the safety of Schwan's proposed standard.

In 1973, Michaelson had submitted testimony to the Senate Commerce Committee supporting a proposal by the Navy to study the effects of the ELF fields given off by Project Sanguine on human volunteers. He told the committee that "it appears entirely possible that these fields are involved in the etiology of certain illnesses which have increased spectacularly during the last century." When he testified at the P.S.C. hearings, however, he said that ELF fields from power lines were safe, and warned that Soviet investigations showing ELF effects should be "viewed with caution." (Soviet scientists had determined that workers in high-

voltage substations were experiencing altered pulse rates and blood pressure, and also fatigue, drowsiness, and headache, and the Soviet government had ruled that 750-kilovolt power lines must be at least a hundred metres from inhabited dwellings—two hundred feet

more than the safety zone that had been proposed for the Massena-to-Marcy line.) As for the thirty-two published studies demonstrating ELF effects, Michaelson suggested that it was "possible to postulate a large number and variety of factors other than exposure to the electrical field as the cause of the observed difference." He also declared that a biological effect did not necessarily constitute a biological hazard, thus implying that an effect could be ignored if it had not been proved to be a menace to health.



A third witness for the utility companies and PASNY was Professor Morton W. Miller, a botanist, who, like Michaelson,

was a member of the Department of Radiation Biology and Biophysics at the University of Rochester's School of Medicine and Dentistry. Miller, who had been a student of Michaelson's, had conducted a three-year study for the Navy on the biological effects of ELF radiation from Sanguine, in which he had determined that bean-plant roots were not affected by exposure to ELF. In the testimony he filed for the P.S.C. hearings he stated that the proposed 765-kilovolt lines "did not pose an unreasonable risk to human health," basing this conclusion largely upon his analysis of studies of Sanguine that, like his own, had produced negative results.

Cross-examination of witnesses began in April of 1976, and took place in a state office building in Syracuse. At the outset, Simpson forced Miller to concede that since the electric field produced by a 765-kilovolt line was far stronger than the field emanating from Sanguine, negative studies of radiation from Sanguine could not be used to demonstrate that the fields from the power line would be safe. He then got Michaelson, who followed Miller to the witness stand, to concede that his position regarding ELF fields from the proposed line was not "what we don't know can hurt us," or "what we don't know can't hurt us," but "what we don't know *might* hurt us"—a rather

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questionable position to take in a hearing concerning the public health.

Michaelson was followed to the stand by Herman Schwan, who had testified in 1975 as an expert for the General Electric Company in hearings conducted by the Food and Drug Administration's Bureau of Radiological Health after the Bureau had ordered the recall of thirty-six thousand G.E. ovens suspected of leaking unacceptable levels of microwave radiation. The Bureau's final report contained an appendix entitled "Undocumented and Unsubstantiated Statements Made by Schwan," which listed more than a hundred such statements. During cross-examination, Simpson forced Schwan to acknowledge that he did not know how or whether the low-intensity current induced in bone by power-line radiation might affect bone growth, the healing of fractures, or the production of bone tumors. Simpson then got Schwan to acknowledge that he could not say how or whether **ELF** fields from power lines might affect other organs of the body, and Simpson asked him how, if he couldn't answer these questions, he could be certain that the proposed line was safe. Finally, toward the end of the second day of cross-examination, Schwan said that he did not wish to continue answering such questions, and at that point Simpson told the administrative judge who was presiding over the hearing that he had no more questions to ask.

Marino was cross-examined for eight days in late April, and Becker underwent cross-examination for four days early in May. Although attorneys for Rochester Gas & Electric, Niagara Mohawk, and **PASNY** claimed that Marino was prejudiced against power companies, and maintained that Becker's testimony should be thrown out, on the ground that it **contained** "the rankest form of hearsay," **neither** man could be shaken from his **conviction** that because **ELF** fields had been shown to produce biological effects in animals they posed a potential **health** risk for human beings. By now, however, Becker and Marino were not **only** locked in a struggle with **PASNY** and the utilities but also engaged in a bitter debate with the National Academy of Sciences. This came about when they learned that the Academy had appointed a committee of experts to look into the biological effects of **ELF** radiation, and that its members in-

cluded Schwan, Michaelson, and Miller.

DURING 1973 and 1974, determined political opposition had driven Project Sanguine from Wisconsin and also from a backup site in the Texas hill country. In 1975, the Navy, in an effort to make its ELF communications system more palatable to the public, proposed to reduce the area that the system would encompass from twenty-two thousand five hundred square miles to between three and four thousand square miles, and renamed it Project Seafarer. The Navy then suggested moving Seafarer to the Upper Peninsula of Michigan, where, because of high unemployment and a depressed economy, it was thought that the project might stand a better chance of being accepted. Tentative approval was given to Seafarer by Governor William G. Milliken, of Michigan, but later he demanded the right to veto the installation of the system, for he had learned that Navy officials had failed to inform his science advisers about the Pensacola study showing that exposure to ELF magnetic fields had raised triglyceride levels in human beings, or about the other biological effects of ELF radiation which had alarmed Becker and the other members of the Navy's 1973 advisory committee.

The report of the 1973 committee did not come to light until December of 1975, when a copy of it was acquired by Senator Gaylord Nelson, of Wisconsin. Nelson was furious at learning that the Navy had withheld the report for two years while some of his constituents were undergoing exposure to ELF at the Clam Lake test facility. In a press release he accused the Navy of suppressing evidence of a potential health risk to the citizens of his state and of failing to perform the follow-up studies of ELF that had been urgently recommended by Becker and the other members of the advisory committee. Seeking to mollify Nelson and to defuse a politically embarrassing situation, the Navy offered the National Academy of Sciences a contract to conduct an inquiry into the possibility that plants, animals, and people might be harmed by the electric and magnetic fields associated with Project Seafarer.

Early in January of 1976, the Academy announced that it had appointed sixteen experts to a Committee on Biosphere Effects of Extremely-Low-

Frequency Radiation, and that the committee would be headed by J. Woodland Hastings, a professor in the Department of Biology of Harvard University. The list of candidates from which the committee members were chosen had been drawn up by members of the National Academy's professional staff, who were said to have relied upon advice from the Navy in compiling it. The list was then presented to Hastings, an affable man who had no experience in ELF research, and whose selections for membership were subject to the approval of high Academy officials. Among those officials was the Academy's president, Philip Handler, who was a biochemist known for his work on amino acids. In keeping with Academy policy at the time, only after the committee had been appointed were its members asked to fill out a so-called bias statement, indicating what views they might have expressed publicly concerning the biological effects of ELF, or whether they might have other conflicts of interest.

When Marino learned that Schwan, Michaelson, and Miller had been named to the Academy committee, he telephoned Hastings to protest that the three men had already submitted testimony to the P.S.C. hearings in New York that ELF radiation from a proposed power line would not harm the health of human beings or pose a hazard to the environment. According to Marino, Hastings expressed surprise at this, and promised to have him and Becker appointed to the committee, in order to give it better balance. At the time, Academy officials defended the makeup of the committee by pointing out that one of its members, Dr. W. Ross Adey, of the Brain Research Institute of U.C.L.A., had opposed Schwan's views concerning the biological effects of ELF fields, and that two other members had served on a Sanguine-evaluation panel in Wisconsin which had been critical of some of the Navy's studies of ELF. Adey was in fact the only person on the committee who

had conducted any significant research on the biological effects of low-level ELF fields. Most of its members had no previous demonstrated experience with ELF studies, and were thus at a disadvantage in assessing or challenging the opinions of Schwan and Michaelson, who were widely regarded as experts in the field, even though their work dealt almost exclusively with higher frequencies. Moreover, several members—among them George M. Wilkening, the director of environmental health at the Bell Telephone Laboratories, in Murray Hill, New Jersey—were staunch advocates of the ten-milliwatt standard.

In August of 1977, the National Academy of Sciences released the final report of the findings of its committee on the biological effects of ELF radiation from Seafarer. The report read in large part like a replay of the opinions and testimony that had been presented by Schwan, Michaelson, and Miller at the P.S.C. hearings. Its authors dismissed Marino's experiments showing stunted growth in rats and mice that had been exposed to ELF radiation, and concluded that "there should be no concern for possible effects of Seafarer on fertility, growth, and development." They found deficiencies in the studies demonstrating that ELF magnetic fields caused elevated triglyceride levels in human beings, and concluded that "Seafarer fields will not have an effect on human triglyceride concentrations." They passed quickly over findings that ELF radiation caused slowed responses' in human beings and monkeys and, ignoring a 1974 report showing that ELF magnetic fields had degraded the ability of human volunteers at the Naval Aerospace Medical Research Laboratory, in Pensacola, to perform simple addition, stated their belief that the behavioral effects of ELF "do not appear to warrant concern." In the end, they found themselves able to assure the public that, except for possible electric shocks, "the likelihood of serious adverse biologic effects of Seafarer is very small." Moreover, after claiming at the outset of their report to be "aware of the larger question" of the potential hazards that might be involved in the exposure of living organisms to ELF fields, such as those emanating from power lines, the members of the Academy committee had not another word to say about this question except to point out in passing



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that "power lines sometimes carry currents much larger than those of Seafarer."

THE long-drawn-out P.S.C. hearings in Rochester had ended in March of 1977, after a second grueling cross-examination of Marino by attorneys for the utility companies and PASNY, who charged that he was biased and irresponsible because he had allowed himself to be interviewed about the power-line controversy by Mike Wallace, of the CBS program "60 Minutes," and because he and Becker had written a letter to Governor Carey in which they described PASNY'S transmission line as an "imminent health hazard." During the rest of the year, administrative-law judges Thomas R. Matias and Harold L. Colbeth, who had presided over the hearings, wrote a recommended decision for the Public Service Commission. Meanwhile, Marino filed an amicus-curiae brief in the case, in which he urged the P.S.C. to take protective measures not only against ELF fields emanating from the proposed 765-kilovolt power lines but also against fields that were being given off by existing 345 kilovolt lines. In his brief Marino declared that "the scientific literature which shows that the proposed transmission lines would be a human health hazard also shows that existing high-voltage transmission lines are a human health hazard." He based his argument upon the fact that many researchers had found biological effects in test animals exposed to the equivalent of up to fifteen hundred volts per metre, whereas the electric-field strength at the edge of the hundred-and-fifty-foot right-of-way of a standard 345 kilovolt line had been calculated to be approximately sixteen hundred volts per metre. Marino proposed that a safety factor of at least one hundred be applied, and that the upper limit of permissible chronic human exposure be set at one hundred volts per metre. He said that to permit exposure to more intense fields would be tantamount to subjecting people to involuntary human experimentation, and he suggested that doing so could make power companies liable for the tort of battery or for that of the taking of a constructive easement over land. He also pointed out that the average transmission line carries only part of its deliverable electric power within its right-of-way—that as much as fifty

per cent of its power exists in measurable field strengths beyond the right-of-way. Marino went on to warn that people living in the vicinity of a 765-kilovolt power line would be exposed to a strong alternating-current magnetic field, whose magnitude would be "totally new and unique with respect to the evolutionary history of life on earth." Finally, he recommended that the P.S.C. require **PASNY** and the utilities to inform the people of New York State of the existence of a valid scientific dispute concerning the hazard posed to human health by exposure to electric and magnetic fields from high-voltage transmission lines, and he urged the P.S.C. to organize a major research program, conducted by independent scientists, in order to determine the extent of the hazard.

On January 20, 1978, Matias and Colbeth handed down their recommended decision—a hundred-and-fifty-seven-page document that reflected considerable ambivalence on their part. On the one hand, nearly a third of it was devoted to an attack upon the credibility and competence of Marino, who was accused of having been "evasive and argumentative under cross-examination," and whose experimental work was described as "not conducted carefully enough for the results to be believable." On the other hand, Matias and Colbeth concluded it was possible that "continuous long-term repeated exposure to electric fields exceeding 2500 volts per meter might result in some biological effects that might be harmful." After selecting a safety factor of only two and a half, they went on to recommend that no person should live or work regularly in areas where the electric field exceeded a thousand volts per metre at one metre above the ground. That meant that a 765-kilovolt power line would require a right-of-way approximately three hundred and fifty feet wide instead of a two-hundred-and-fifty-foot-wide corridor, which was what had been proposed by **PASNY** and the utility companies.

As might be expected, the decision of the administrative-law judges pleased none of the parties to the hearings. **PASNY** and the utility companies objected to the recommendation that would require them to create wider rights-of-way, and P.S.C. staff members faulted them for omitting any detailed consideration of the thirty-two

studies Marino had cited. The P.S.C. staff claimed that nine of these studies provided "a solid body of evidence that electric fields from the transmission line will probably cause biological effects in humans." For this reason, they recommended that the Public Service Commissioners establish a four-hundred-volt-per-metre level for maximum human exposure. They also recommended that the utilities be required to inform each resident living adjacent to the right-of-way of a 765-kilovolt line that there was a risk from exposure to electromagnetic fields, and they proposed that anyone living within two hundred and seventy-five feet of the centerline of the right-of-way of a 765-kilovolt power line be given an option to have his house purchased or relocated if the electric field outside the dwelling exceeded the four-hundred-volt-per-metre level.

The final decision in the power-line case came in June of 1978, when, after reviewing the hearing record and the recommended decision of the administrative-law judges, the six members of the Public Service Commission issued a seventy-four-page opinion. It straddled the public-health issue. To begin with, the commissioners found that although the hearing record did not show that the electric and magnetic fields of the proposed 765-kilovolt lines would endanger human health and safety, "it contains unrefuted inferences of possible risks that we cannot responsibly ignore." They based their assessment of possible risk on Marino's three-generation mouse study and on the other studies showing that **ELF** fields produced biological effects in test animals, and they declared that "these effects cannot be presumed harmless." They went on to dismiss allegations that Marino's experiments were flawed, pointing out that **PASNY** and the utilities "could have aided the record by attempting to replicate Dr. Marino's experiments in a manner free of the defects they perceived in them" but that "for reasons best known to them,

they did not do so." As for the harsh criticism levelled against Marino by Matias and Colbeth, the commissioners let stand the finding of their staff that **PASNY** and the utility companies had mounted "vigorous efforts to discredit him [which] were more suitable to a slander trial than a fact-finding, scientific investigation."

However, it was one thing for the commissioners to agree with Marino and Becker that **ELF** fields could cause biological effects in test animals and quite another for them to decide how far to go in protecting the public health against the potential threat posed by power-line radiation. Unlike Matias and Colbeth, they could not very well ignore the question of how safe the existing 345-kilovolt transmission lines might be, when their own staff had recommended a four-hundred-volt-per-metre level for maximum human exposure, and when people living in houses adjacent to the rights-of-way of 345-kilovolt transmission lines were already being exposed to electric-field strengths well above that level. The staff proposal posed a quandary for the commissioners. They were already under pressure from the utilities to make certain that power lines operating at lower voltages would be exempt from any standard they might adopt for 765-kilovolt lines, and they apparently feared that if they adopted the four-hundred-volt level, or the staff's recommendation that people living adjacent to the power-line right-of-way be warned of the possibility of a health risk, they might create widespread panic and a public furor. In the end, they attempted to solve the problem by declaring that the right-of-way of a 765-kilovolt transmission line should be wide enough so that the strength of the electric field at its edge was no greater than the electric-field strength (about sixteen hundred volts per metre) that had been calculated to exist at the edges of the rights-of-way of standard 345-kilovolt lines. "In this way," they reasoned, "we assure that the risks, if any, of long-term exposure to 765 kV transmission in the areas traversed by **PASNY'S** line and any future 765 kV lines will be no greater than those, now widely accepted, of long-term exposure to the 345 kV lines operating throughout the State."

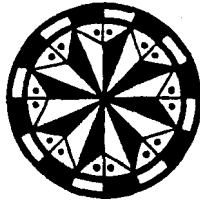
The sweeping supposition of the phrase "now widely accepted" appeared to trouble the commissioners,



for they acknowledged in a footnote that "we do not imply that society has, in any way, explicitly decided that 345 kV lines are worth whatever risks they may entail." Whatever the commissioners wished to imply, thanks to inadequate coverage of the power-line hearings by the media the public had been given almost no information about the risk posed by power-line radiation, let alone enough information to reach any kind of rational decision. Anyone who chose to read to the end of the P.S.C.'s opinion, however, would have come upon a dissent filed by Commissioner Harold A. Jerry, Jr. He put an astute finger on the motive behind the decision of his five colleagues to extend the presumption of benignity to 345-kilovolt power lines.

"I believe that the majority has settled for this width because of irrelevant concern over the widths of existing 345 kV rights-of-way, rather than because of concern for the proper widths of 765 kV lines in view of the evidence in this case," Jerry wrote. "In other words, the majority has been swayed by the problem of what to do with existing 345 kV lines if it adopts a 765 right-of-way with weaker field strengths at its edges than those present at the edges of existing 345 kV rights-of-way."

In spite of temporizing on the question of the safety of 345-kilovolt lines, the P.S.C. opinion was a major decision, because it marked the first time that any regulatory body in the nation had gone on record as stating that studies showing that ELF fields could cause biological effects in animals must raise questions about human exposure to such fields along power-line rights-of-way. Moreover, the commissioners were sufficiently troubled by the many unanswered questions concerning ELF radiation to take the unprecedented step of calling for a five-year research program on the biological effects of power-line fields, which was to be financed by PASNY and the utility companies and carried out by independent scientists. A few months after the commissioners issued their decision, PASNY brought suit against the P.S.C., claiming that the commission had no right to require it to participate in such a program as a condition of certifying a transmission line. In 1979, the appellate division of the New York State Supreme Court upheld PASNY's posi-



tion in the matter, but in 1980, while that decision was on appeal to the State Court of Appeals, the P.S.C. and PASNY reached a settlement, under which PASNY and seven major electric-utility companies agreed to provide five million dollars to finance a five-year research program that would be known as the New York State Power Lines Project. A three-member board, made up of the commissioner of the New York State Health Department, the chairman of PASNY, and the chairman of the P.S.C., was given responsibility for establishing the project, and early in 1981 the board selected a ten-member scientific advisory panel to develop the project's research program and oversee its research contracts.

On the face of it, the decision of the Public Service Commissioners and the subsequent settlement of the legal dispute between PASNY and the P.S.C. seemed to indicate that Becker and Marino had finally prevailed in their long struggle. As a result of their stand, the Power Authority would soon announce that it intended to postpone indefinitely the construction of any more 765-kilovolt lines, and Rochester Gas & Electric and Niagara Mohawk would eventually be denied permission to build their proposed 765-kilovolt line from Rochester to Oswego. By that time, however, Becker and Marino had become the target of savage criticism and had been forced out of the Veterans Administration.

In 1964, Becker had won the Administration's coveted William S. Middleton Award for outstanding achievement in medical research, and in 1971 the V.A. had granted him the status of medical investigator, which meant that he could put aside his clinical duties and devote all his time and energy to research. In April of 1976 however, just as he was about to take the stand for the first time in the power-line hearings, he was informed by the V.A.'s assistant chief medical director for research and development in Washington, that his application for a five-year renewal of his medical investigatorship had been deferred. Later that year, a research grant that he had been receiving from the National Institutes of Health was discontinued, and from then on he began to experience great difficulty in getting his research proposals approved by the

V.A. Becker managed to keep his laboratory going for three more years by finding an alternative source of funding at the V.A. In 1980, a year after he won the Nicolas Andry Award of the Association of Bone and Joint Surgeons for outstanding achievement in the field of orthopedic surgery, all his V.A. grants were terminated, and Becker retired and went to live in Lowville, where he now directs a research-and-consulting firm called Becker Biomagnetics. Six months after his retirement, his research laboratory, which had been operating for twenty years, was shut down. Shortly thereafter, Marino, who had worked in the lab for seventeen years, was told that there were no suitable positions for him at the hospital. As a result, he resigned from the Veterans Administration and went to Louisiana, and he is now a professor in the Department of Orthopedic Surgery of the Louisiana State University Medical Center, in Shreveport.

Although the motives behind the apparent vendetta that was carried out against Becker and Marino can only be guessed at, it seems clear that their outspokenness regarding the health hazard of power-line radiation had something to do with it. Moreover, after the 1978 P.S.C. decision the two men came under heavy attack from other quarters. In 1979, Professor Hastings, who had chaired the National Academy of Sciences' committee on Seafarer, told Susan Schiefelbein, who was writing an article about the ELF controversy for *The Saturday Review*, that Marino and Becker had not conducted any research on the biological effects of ELF, and that the judges in the power-line hearing had decided against them. "The judges threw out the case with prejudice," Schiefelbein quoted Hastings as saying. "[They] ruled that Marino's not a believable witness, that he's evasive and deceitful. Here we were, being attacked by people who ultimately were thrown out of a court of justice in that way. They've all been thrown out. These guys are all a bunch of quacks."

Another attack upon Marino was mounted by Philip Handler after the publication of Schiefelbein's article, in September of 1979. Her article was entitled "The Invisible Threat: The Stifled Story of Electric Waves," and it was highly critical of the makeup and conduct of the National Academy's

committee on Seafarer and of the credibility of Professor Hastings. A few months after it appeared, Handler wrote to Carl Tucker, the editor of *The Saturday Review*, threatening to sue the magazine unless Tucker published an article entitled "Scientific Evidence and Public Decision Making," which Handler had written with the assistance of two senior officials of the National Academy. In the article Handler and his colleagues criticized Marino and praised Schwan, and concluded that in the absence of proof of a hazard, or of any acceptable theory predicting a hazard, "we are left with the unprovable negative: that there does not exist any danger from extremely low frequency radiation at the level at which people are customarily exposed." They then lashed out at the press for using "the thin tissue of fancied biological effects of ELF to inflame the imagination of the public."

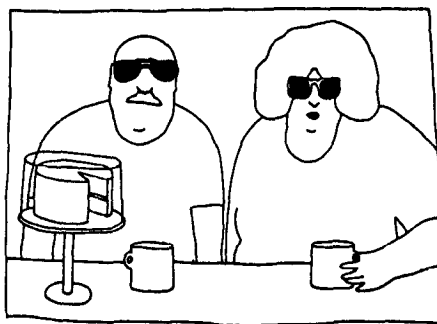
In the end, Tucker stood by the article that Schiefelbein had written, and the piece by Handler and his associates went unpublished in *The Saturday Review*. Handler's article, however, exemplified the thinking with regard to the power-line problem at the highest level of the nation's scientific establishment at the time that Nancy Wertheimer discovered the association between childhood cancer and exposure to alternating magnetic fields from ordinary electrical-distribution lines—a finding she hoped that the medical and scientific community would be eager to investigate in greater detail.

IN October of 1979, an application that Wertheimer had submitted to the National Institutes of Health for a grant to study the possible association between cancer in adults and exposure to magnetic fields from high-current wiring was rejected. "I was disappointed, of course, but I didn't let it get me down," she said recently. "As it happened, I had been gathering data

for the adult study for almost a year, so I just kept right on going, and did it the way I had done the childhood study—on my own time and with my own money."

To begin with, Wertheimer collected death certificates for people who had died of cancer between 1967 and 1975 in the towns of Boulder and nearby Longmont, and also 1977 cancer-death certificates for residents of the city of Denver and of its suburbs. These four samples also included cancer survivors—people who had been found five or more years previously to have a life-threatening form of cancer and who in 1979 were still living without known recurrence of the disease. In each of the samples, only those cancer victims known to have lived in the sampling area for at least four years prior to diagnosis were retained for the study. Control addresses for the cancer victims from Boulder and Longmont were selected from non-cancer-death certificates in the same towns, and the control addresses for the Denver and Denver-suburb cancer cases were chosen at random from within the same neighborhoods there. By the spring of 1979, Wertheimer had collected addresses for eleven hundred and seventy-nine cancer victims and the same number of controls, and for most of that summer and the next she drove around—often from sunrise to sunset—visiting case and control homes and classifying each of them according to her wiring-configuration code, which she had refined somewhat since the childhood study.

"One reason I had hoped to get an N.I.H. grant was so that I could afford to hire someone to do the coding of the addresses blind—in other words, someone who, unlike me, would be totally unaware of which addresses had been the residences of cancer victims and which the homes of controls," she says. "In that way, I could have insured that no bias could creep into the final results because of not-blind coding. Without financial support, however, that was impossible, so I hired a researcher out of my own pocket to do blind coding of a hundred and forty of the eleven hundred and seventy-nine case-control pairs. When it turned out that the researcher's blind coding did not differ greatly from my own coding, and that a significant result was obtained from the blind-coded sample alone, I was reassured about using my not-blind



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coding in the final analysis of the data.”

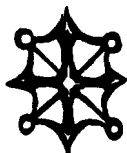
While Wertheimer was busy gathering information for her adult study, the utilities industry was trying to decide how to respond to the disturbing findings of her childhood study. In July of 1979, she and Leeper were visited in Boulder by Robert Kavet, the project manager for biomedical studies at the Electric Power Research Institute (EPRI), an organization situated in Palo Alto, California, that is sponsored by major utility companies across the nation. Kavet discussed the childhood-cancer study at considerable length with Wertheimer and Leeper, and after he returned to Palo Alto he wrote a report on his visit and sent it, on July 30th, to EPRI's member companies, with a copy to Wertheimer. In the report he described the dilemma that their findings posed for the electric-utilities industry. On the one hand, he wondered how magnetic fields in the milligauss range could possibly correlate with increased cancer rates in the absence of a body of scientific evidence to support the existence of such a relationship. On the other hand, he pointed out that the childhood-cancer study had been peer-reviewed and published in the highly esteemed *American Journal of Epidemiology*. Kavet suggested that the utilities industry measure magnetic fields inside a representative number of dwellings in Wertheimer's study to determine what magnetic-field exposures were actually found inside the homes. “This is a complex issue, and one that has stirred interest and controversy,” he wrote in conclusion. “I do not believe that any single person has the solution, but collectively we might be able to pool our insights.”

On August 10th, Wertheimer wrote to Kavet and thanked him for sending her a copy of the report. “As you say, the question of what to do next is complex,” she agreed. “I rather doubt that much will happen so long as our one study is the only suggestive evidence in a sea of disbelief. However, we'd be glad to help in any way we could if you did decide on a study project.” Wertheimer then cautioned Kavet regarding his suggestion that the electric-utilities industry measure in-house magnetic fields. “You recall the misunderstanding (which you shared with us and many others) about

the magnetic fields from appliances as reported in the Sanguine studies,” she wrote. “Their magnetic-field readings were taken as close as possible to the appliance housings, and so give a highly exaggerated idea of what ambient fields might be expected within the homes from appliance sources. I'm enclosing our correspondence with them on this matter.”

The enclosed correspondence consisted of a letter that Leeper had written in February of 1978 to Dr. Donald A. Miller, of the Naval Underwater Systems Center, in New London, Connecticut, with a copy to Dr. Anthony R. Valentino, the manager for *electromagnetic* effects at the Illinois Institute of Technology Research Institute (I.I.T.R.I.), in Chicago, and a letter of reply that Valentino had written to Leeper in his own behalf and Donald Miller's, (Miller had worked at I.I.T.R.I. when it was under contract to the Navy to produce the 1972 final environmental-impact statement for Project Sanguine, and, together with Valentino, he had helped write the statement before going to the Naval Underwater Systems Center.) Leeper reminded Miller in his letter that although the impact statement declared that I.I.T.R.I. had measured very strong magnetic fields in the vicinity of ordinary consumer appliances, such as hair dryers, television sets, and fluorescent lamps, Miller had subsequently acknowledged in a telephone conversation with Leeper that he had been able to measure strong magnetic fields only when he held the detector coil very close to each appliance.

Early in March of 1978, Valentine wrote Leeper, “I have discussed your letter with Dr. Miller and we both agree with your concern over the possible misinterpretation of measurement taken as near as possible to various appliances, as compared with other measurements taken at some distance.” In 1983, however, almost two years after President Reagan and Secretary of Defense Caspar W. Weinberger had ordered the Navy to proceed with the development of Project ELF (a Sanguine/Seafarer was now called) I.I.T.R.I. and the Navy issued a report, entitled “Representative Electromagnetic Field Intensities Near the Clam Lake ELF Facility,” that claimed once again that strong magnetic field



up to twenty-five gauss had been measured at "user distances" from hair dryers and other household appliances. Not until the following year did I.I.T.R.I. prepare a report for the Naval Electronics Systems Command, entitled "Household Appliance Magnetic Field Survey," that finally showed (as Wertheimer and Leeper had been claiming for nearly a decade) that magnetic fields from household appliances dropped off so rapidly that the devices could not be considered major sources of ambient indoor magnetic-field exposure. By that time, the Navy had received permission to rebuild and reactivate the ELF transmitter at Clam Lake, and to construct an ELF transmitter near the K. I. Sawyer Air Force Base, on the Upper Peninsula of Michigan.

BY 1981, the power companies had apparently decided that the best way out of their bind was to try to discredit Wertheimer. Early in January, EPRI awarded a contract to H. Daniel Roth, of Roth Associates—a consulting firm in Rockville, Maryland, that had done work for Consolidated Edison, of New York, and other utility companies—to reanalyze Wertheimer and Leeper's childhood-cancer study. Shortly thereafter, Roth called Wertheimer and asked her if she would be willing to supply him with the data she had used in conducting the study, and on January 7th she wrote to him with a copy to Kavet to say that she was "uneasy" about the scope of his request, because she had limited resources and was very busy writing a report of her investigation of magnetic fields and cancer in adults. "I don't want to be uncooperative, and I believe that scientific data should be freely shared," she said. "But I honestly doubt that reanalysis of our data will yield any important new information. EPRI could use its funds more effectively, I should think, in financing a replication of our work, using whatever controls they deem appropriate." Wertheimer then told Roth, "I am left with the impression that, at present, EPRI's main concern is to find some procedural or statistical criticisms with which to refute our study, rather than to investigate vigorously the possibility of adverse magnetic field effects."

Together with the copy of her letter to Roth, Wertheimer sent Kavet a

letter offering to supply him and Roth with more of her data once she had finished writing the paper on magnetic fields and adult cancer. Three months later, on April 7th, she wrote again, telling Kavet that Roth had called with questions about the data and she had supplied the answers. She added that he or Roth wanted more information on the childhood-cancer study, "this is the time when I might best be able to provide it."

Unbeknownst to Wertheimer, Roth had already finished a draft of a seven-page report criticizing her study, and was about to submit it to Kavet. After receiving it in April of 1981, Kavet held on to it for fourteen months, and then, in June of 1982, sent it (still in draft form) to Greg Alvord, who was the scientific-research coordinator for the New York State Health Department's Power Lines Project. The timing was interesting. New York health officials had just announced that they might try to replicate Wertheimer's childhood-cancer study but would wait until they had reanalyzed its data before doing so.

Roth began his report by questioning Wertheimer's suggestion that workers who were frequently exposed to alternating-current magnetic fields had developed cancer at a significantly higher rate than the population as a whole. Roth declared that this was doubtful because "the type of excess cancer deaths which occurred are those not normally associated with exposures to electric fields." As for Wertheimer's findings linking childhood cancer to high-current wiring, Roth claimed that they were "almost impossible to evaluate," because they were "based on questionable statistical calculations." He went on to challenge the manner in which she had analyzed the development of cancer in relation to the amount of current that could be expected from the various types of wires in her wiring-configuration code. He also criticized her for failing to take into account other factors, such as exposure to pollution, when she selected the control population for her study. In conclusion, he asserted that because her selection of controls "might have been biased," and because her wiring-configuration code "might have been incorrect," it was "doubtful that we will ever be able to properly evaluate Wertheimer's study

findings." He added, "We feel it is important for the utility industry to conduct a more comprehensive and controlled study of the Denver area and to study other geographical locations as well."

When Andrew Marino sent a copy of Roth's report to Wertheimer, in August of 1982, she fired off a four-page letter to Kavet, telling him that Roth was wrong to say that the childhood-cancer study linked cancer with exposure to electric fields when in fact the link was with magnetic fields. As for Roth's suggestion that the type of excess cancer deaths she had found were "not normally associated with exposures to electric fields," Wertheimer observed that such a statement "implies that there are some types of cancer which are recognized to be so associated," and inquired of Kavet, "Do you know something I don't know about this?" In conclusion, she told Kavet that she agreed fully with Roth's call for the utilities industry to conduct additional studies, and offered to help Kavet and EPRI "in any such project you may devise." The following month, she wrote to Kavet again, calling his attention to a report recently published in *The New England Journal of Medicine* which linked the development of leukemia to occupational exposure to electric and magnetic fields.

The report to which Wertheimer referred appeared in the July 22, 1982, issue of *The New England Journal* as a letter to the editor from Dr. Samuel Milham, Jr., a physician and epidemiologist working for the Washington State Department of Social and Health Services, in Olympia. While updating an earlier study he'd done of occupational mortality, Milham examined the data for four hundred and thirty-eight thousand deaths occurring among workingmen in Washington between 1950 and 1979, and he noticed that among men whose occupations required them to work in electric or magnetic fields there were more deaths caused by leukemia than the proportionate mortality ratio (P.M.R.) in the general population would lead one to suspect. Indeed, the P.M.R. for leukemia was elevated in ten out of eleven occupations he investigated which were linked to electric or magnetic fields. The excess was most striking among aluminum-reduction workers, who are exposed to strong magnetic fields induced by high-amperage direct



current, which is used during the reduction process, and who experienced twice as many deaths from leukemia as had been expected. Leukemia deaths were also significantly higher among electricians, power and telephone linemen, power-station operators, and motion-picture projectionists. (The latter work near step-up transformers that emit strong magnetic fields.)

On November 20, 1982, *The Lancet*, in England, which is one of the most highly regarded medical journals in the world, published a letter reporting that Milham's findings had been supported by the results of an investigation conducted by three physicians in the Department of Family and Preventive Medicine at the University of Southern California's School of Medicine, in Los Angeles. The California researchers had reviewed cases of leukemia in men from Los Angeles County who were listed as having jobs that entailed exposure to electric or magnetic fields, and had discovered that the incidence of acute leukemia and acute myeloid leukemia among them, and especially among power and telephone linemen, was significantly

higher than might have been expected. Close on the heels of the Los Angeles study came the results of an investigation into mortality from leukemia among electrical workers in England and Wales. The study was conducted by Michael E. McDowall, an epidemiologist working in the medical-statistics division of the Office of Population Censuses and Surveys, in London, and its results were published in *The Lancet* on January 29, 1983. McDowall had analyzed five hundred and thirty-seven deaths from acute myeloid leukemia and had found a consistently increased risk of the disease among all electrical occupations, the highest risk being among telecommunications engineers. An editorial that appeared in the same issue of *The Lancet* called attention to the fact that McDowall's findings followed those of Wertheimer and Leeper, Milham, and the three researchers from the University of Southern California, and observed that "the cluster of reports relating to acute myeloid leukemia is worrisome." The editorial went on to say, "Since all of us are exposed to some electrical and magnetic fields, and

continuously to low levels of non-ionizing electromagnetic radiation, it is important to know what risks, if any, are entailed."

During the next three years, an excess risk of leukemia was discovered among electrical workers in New Zealand, Canada, and southeastern England, and among coal miners in the United States, who are intimately exposed to electromagnetic fields from power lines and transformers in tunnels and other closely confined areas. Indeed, by early 1986 fifteen out of seventeen surveys of electrical and electronics workers around the world showed a link between exposure to electric and magnetic fields and the development of cancer. Among them was a 1984 study showing that a significantly higher than expected number of white male residents of Maryland who had died of brain tumors between 1969 and 1982 had been employed in electrical occupations—electricians, electrical or electronics engineers, and utility servicemen. Further corroboration of this link came in 1988, when a study of men who had died of brain cancer in East Texas

between 1969 and 1978 showed a significantly elevated risk for those men working in the communications, utilities, and trucking industries. Indeed, the risk for electric-utility workers was thirteen times that for workers who were not exposed to electromagnetic fields.

Milham's 1982 report in *The New England Journal of Medicine* and its subsequent corroboration by researchers in many countries finally began to arouse the members of the medical and scientific community from their lethargy concerning the health hazards of ELF fields. Samuel Milham is a tall, brown-eyed, dark-haired man of Lebanese descent, who was born in Albany, New York, in 1932. He got his medical degree from Albany Medical College in 1958, and in 1961 he received his master's degree in public health from the Johns Hopkins University School of Hygiene and Public Health. He then worked for five years as an epidemiologist for the New York State Department of Health, in Albany. There he set up a congenital-malformation-surveillance system in the state, which was based on routine examination of birth and stillbirth certificates and other vital records. It was the first such system to be established in the United States, and its success was soon measured by its quick detection of congenital malformations caused by use of the drug thalidomide.

During the early nineteen-seventies, Milham, who had gone to work in the Washington State Department of Social and Health Services in 1968, analyzed more than three hundred thousand death certificates of male workers in the state who had died between 1950 and 1971, and coded the occupation and the employer of each of them. One of the major findings of this analysis, which was partly financed by the National Institute for Occupational Safety and Health, in Cincinnati, was that workers in the half-dozen aluminum-reduction plants then operating in Washington State were dying at a significantly increased rate of cancer of the lymphatic system and the pancreas. After several major aluminum producers refused requests from Milham that he be allowed to conduct follow-up studies of their workers, Dr. James P. Hughes, who was the medical director of the Kaiser Aluminum & Chemical Corporation, of Oakland, California, encouraged him to inves-

tigate the mortality among the workers at the company's Kaiser Mead aluminum-reduction plant, in Spokane. Milham quickly found that men in this plant were dying at an increased rate of lymphoma, Hodgkin's disease, and benign brain tumors.

"The fact that there was no great increase in lung cancer among these workers-especially those in the pot rooms-surprised and puzzled me," Milham said recently. "Aluminum-pot-room workers are exposed to benzopyrene -the culprit in cigarette smoking-because coal-tar pitch is used as a binder for carbon in the electrolytic reduction process. At the time I did my study, the prevailing wisdom in the aluminum industry blamed coal-tar pitch for the excess cancers in aluminum workers I had found. But although coal-tar pitch had long been recognized as a potent carcinogen, it had never been associated with lymphoma, so I knew that it couldn't explain why the pot-room workers were dying of lymphoma at about six times the national average, and that I would have to look elsewhere for an answer to the problem. One thing that jumped out at me was the fact that the pot-room workers were exposed to extremely powerful magnetic fields. These fields are generated by the tremendous, ~~seventy-five~~ thousand-plus-ampere direct current that powers the electrolytic process, during which aluminum oxide is reduced to molten aluminum-they are strong enough to tear a monkey wrench out of a man's hand. For this reason, I decided to look through the death certificates of all adult-male deaths in Washington State between 1950 and 1979 to see if deaths from non-Hodgkin's lymphoma, as well as leukemia, might be linked to occupations with exposure to electromagnetic fields. The results of that analysis were the findings I published in *The New England Journal of Medicine* in the summer of 1982. I've since learned that non-Hodgkin's lymphoma is a type of tumor that often develops in people who have impaired immune systems, so it may turn out that magnetic

fields promote cancer by weakening the immune system."

Not long after his letter appeared in the *Journal*, Milham undertook to study causes of death among: members of the American Radio Relay League, with headquarters in Newington, Connecticut, a national group of a hundred and forty thousand amateur radio operators whose hobby exposes them to electromagnetic fields. By acquiring back issues of the League's monthly magazine and reading the obituary sections, he learned the names of two hundred and ninety-six male members from Washington State and sixteen hundred and forty-two male members from California who had died between 1971 and 1983. After obtaining death certificates for two hundred and eighty (some ninety-five per cent) of the Washington State members, and for fourteen hundred and eleven (about eighty-six per cent) of the California members, he analyzed the causes of death for the combined total of sixteen hundred and ninety-one according to the proportionate mortality ratio for 1976, and found excess leukemia among the radio operators. Particularly striking was the fact that deaths from acute and chronic myeloid leukemia were nearly three times as prevalent among these men as they should have been, whereas deaths from chronic lymphatic leukemia were not particularly elevated. This was significant, because acute and chronic myeloid leukemia are known to be caused by exposure to ionizing radiation, whereas chronic lymphatic leukemia is not as a rule caused by ionizing radiation. Also striking was the fact that ninety-seven -some thirty-five per cent-of the two hundred and eighty death certificates from the Washington State amateur radio operators listed occupations for them such as electrician, electronics technician, and radio operator, whereas those occupations account for only about three per cent of male deaths in the Washington State death file.

AT the same time that Wertheimer called Kavet's attention to Milham's study, she sent him preliminary data from a recently completed Swedish study that supported the association she had found between the development of cancer in children and the proximity of their homes to high-current wiring. The Swedish study had been conducted by Dr. Lennart



Tomenius, a medical officer with the **County** of Stockholm. When he began his investigation, in the fall of 1979, he realized that Wertheimer's results might not apply in the County of **Stockholm**, because most of the electricity there is transported (as it is in **New York City** and many other metropolitan sections of the United States) in buried cables made up of closely packed and parallel distribution wires, whose current flow often tends to cancel out the magnetic fields they generate. Since **Tomenius** could not use a wiring-configuration code in these circumstances, he decided to measure the strength of the alternating fifty-hertz magnetic field outside the entrance door of each of the birth and diagnosis dwellings of young Swedish cancer victims, and to take note of any high-tension wires carrying between six kilovolts and 200 kilovolts, and also of any power substations, transformers, and electrified railways and subways that might be visible within a hundred and fifty metres of those homes. (In Sweden, as in most European countries, electricity is generated at fifty rather than sixty hertz.) He then collected the addresses at the times of birth and diagnosis of cancer for seven hundred and sixteen children up to the age of eighteen who were born in Stockholm County, and for each of these young cancer victims he selected a control individual, matched according to age, sex, and church district of birth.

In the end, Tomenius surveyed a total of two thousand and ninety-eight dwellings of cases and controls. He found that a hundred and ninety-six of these dwellings were within a hundred and fifty metres of high-tension wires, power substations, transformers, or electrified railways or subways, and that forty-five of them were within that distance of a 200-kilovolt transmission line. The average strength of the alternating-current magnetic fields measured at the entrance doors of the dwellings near the 200-kilovolt wires was 2.2 milligauss. When Tomenius analyzed his data, he found that twice as many of the homes of children who had developed cancer were near 200-kilovolt lines as were the homes of control children. Similarly, the incidence of cancer in children who lived in forty-eight homes where magnetic fields of three milligauss or more were measured was twice

as high as that in control children.

Tomenius's study was not officially published until 1986, when it appeared in the journal *Bioelectromagnetics*. However, he gave a preliminary report of his findings at the International Symposium on Occupational Health and Safety in Mining and Tunnelling, which was held in Prague, in June of 1982, and it was this presentation that Wertheimer sent to Kavet at EPRI in September. As might be expected, she had a special interest in the results of the Swedish study. "It feels good not being out there alone anymore," she told Louis Slesin, the founder and publisher of *Microwave News*-a monthly report on non-ionizing radiation that is published in New York City-who interviewed her that autumn.

Obviously, Milham's findings and the Swedish study put pressure on officials of the New York State Department of Health and the members of the Power Lines Project's scientific advisory panel to have Wertheimer's childhood-cancer study replicated. Meanwhile, Wertheimer and Leeper had concluded their investigation of adult cancer and submitted a paper entitled "Adult Cancer Related to Electrical Wires Near the Home" to the *International Journal of Epidemiology*, put out by Oxford University Press, and publication was scheduled for December. When Wertheimer finished analyzing the data they had collected, she found that "the homes of cancer patients outnumbered control homes most clearly in the VHCC [very high current configuration] category, with the proportion of cancer homes diminishing over succeeding categories." She went on to say that "this suggests that a dose-relationship may exist between AMF [alternating magnetic field] exposures in this range and cancer," and she pointed out that the association between wires carrying high current and cancer "is quite clear and highly significant for cancer occurring in adults before age 55, but is much less impressive for cancers occurring at older ages." Wertheimer also found that people living near wires that carried very high current developed cancers of the nervous system, uterus, and breast as well as lymphomas more readily than people living near wires that carried lower current, or living far from any wires.

In a section of her paper entitled



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"Discussion," Wertheimer analyzed her observations:

In this study, adult cancer was found to be associated with residence at an HCC address. Although the association was highly significant, it was considerably weaker than the similar association we observed for childhood cancer. This does not necessarily mean that AMFs affect adults less than they do children; rather, it seems likely that, in adults, the years of exposure to environmental carcinogens, as well as to AMFs from various sources, all may affect cancer rates so strongly that the effect of residential HCCs is frequently obscured.

In general, a small increment in cancer, occurring against a relatively high overall cancer rate, is difficult to demonstrate. Where the background cancer rate is low, however, that same increment will be more visible. Thus if there is a modest increase in cancer rate due to HCCs, it should be most visible in children, where cancer is generally rare; and it should also be more visible in young adults, where cancer is still relatively uncommon, than in older adults where cancer is frequent. This is essentially what we observed.

In the spring of 1982, Wertheimer sent an advance copy of the adult-cancer study to Greg Alvord, at the New York State Health Department, and early in 1983 the members of the Power Lines Project's scientific advisory panel commissioned Annemarie F. Crocetti, an epidemiologist and a clinical associate professor in the Department of Community and Preventive Medicine of the New York Medical College in Valhalla, New York, to evaluate Wertheimer's work; and determine whether it warranted further investigation by the Power Lines Project. Crocetti, who received her doctorate in public health at Johns Hopkins, is highly regarded as an expert in the toxicity of heavy metals, such as cadmium, lead, and nickel, and she has long been active in efforts to reduce lead-levels in air, soil, water, and food. In February, she travelled to Boulder and met with Wertheimer over a period of several days to discuss in detail the methodology, analyses, and results of the investigations that Wertheimer and Leeper had conducted. When she returned to New York, she told the scientific advisory panel that Wertheimer's data collection was "extraordinarily meticulous," but that she found the adult study to be flawed in terms of its selection of controls and in how it defined the length of time to which its subjects had been exposed to alternating-current magnetic fields. The childhood study, she felt, "presents relatively few prob-

lems," and she recommended that it be replicated as part of the Power Lines Project's research program. She also recommended that gaussmeter measurements of indoor magnetic fields be made, in order to validate Wertheimer's concept of using wiring configuration to determine their strength.

Shortly after Crocetti submitted her report, the members of the scientific advisory panel accepted her recommendation that the childhood-cancer study be done again, and also decided to look into Milham's finding that adult leukemia was associated with exposure to alternating-current magnetic fields. In September, they awarded a contract for a study of adult cancer to the Battelle Pacific Northwest Laboratories, and a contract for a replication of the childhood-cancer study to David A. Savitz, an epidemiologist at the University of Colorado's School of Medicine, in Denver. In doing so, they were fully expecting (as Dr. David O. Carpenter, the director of the New York State Health Department's Wadsworth Center for Laboratories and Research, who had been placed in charge of the Power Lines Project, later admitted) that Wertheimer's findings would not hold up, and that the new studies would finally lay them to rest.

NEARLY ten years had elapsed since Becker and his six colleagues on the Navy's advisory committee reviewed evidence that **ELF** electric and magnetic fields from Project Sanguine might adversely affect human health, and warned that a large segment of the nation's population might be exposed to even stronger fields from electric-power transmission lines. During that time, dozens of experimental studies here and abroad had shown that **ELF** electromagnetic fields produced biological effects in test animals, and the epidemiological studies by Wertheimer and Leeper, Milham, Tomenius, and others had suggested that alternating current magnetic fields might be a cause of cancer in human beings. Doubters in the medical and scientific community had challenged the epidemiological studies on the grounds that they contained insufficient data on the intensities of the magnetic fields encountered in residential and occupational exposure, and that other potential causes of cancer, such as pollution, genetics, and diet, had not received adequate consideration. What **both** there

them most of all was the lack of any theoretical ground upon which to support the hypothesis that the weak electric and magnetic fields generated by power lines could interact with biological systems at all, let alone pose a threat to human health.

As it happened, information that would help to explain the observed effects of power-line radiation had been in the process of development since the early nineteen-seventies, thanks to the pioneering efforts of an Australian-born scientist, Dr. W. Ross Adey, who had served on the National Academy of Sciences' committee that evaluated Seafarer. Together with colleagues at the Brain Research Institute of U.C.L.A., he had been investigating the interaction of weak electromagnetic fields with the outer membranes and the inner workings of brain cells. Adey is a lanky, brown-eyed man of sixty-seven with wispy gray hair falling over his ears, and a craggy, weather-beaten face. He has a wry sense of humor, a combative streak, and a marked inability to suffer fools gladly—indeed, a strong tendency not to suffer them at all—and he has not only lived the controversy, uncertainty, cover-up, and political infighting that for two decades have characterized the field in which he works but also emerged as its leading theoretician and philosopher.

Adey was born and grew up in Adelaide, in South Australia. Like many children of the twenties, he was fascinated by radio, and as a teen-ager he built a large radio receiver and used it to record signals from the planet Jupiter. In 1939, he entered the University of Adelaide Medical School, and after receiving his bachelor's degree in medicine, in 1943, he served for two years as a surgeon lieutenant in the Australian Navy, where he became familiar with the techniques of radar. Following his service in the Navy, he went back to medical school in Adelaide and received his doctorate in 1949. He then went to England, and spent the next two years as a research fellow at Oxford University, studying anatomy and the physiology of the limbic system—the portion of the brain that is concerned with the expression of emotional and sexual behavior. It is also associated with memory, and damage to the limbic system can result in severe memory loss. After returning to Aus-

tralia for three years, he came to the United States in 1954 and went to work as a professor of anatomy and physiology in the Department of Anatomy at U.C.L.A., and in 1961 he joined the university's newly formed Brain Research Institute.

During the early nineteen-sixties, Adey did groundbreaking work on the radio transmission of brain waves, placing in the skulls of test animals tiny transmitters that broadcast their electroencephalographic (EEG) waves to receivers. In 1965, he became the director of the newly established Space Biology Laboratory at the Institute, and over the next two years he and his colleagues performed extensive computer analyses of the EEG patterns of fifty astronaut candidates from the National Aeronautics and Space Administration.

Thanks to a series of experiments performed a few years earlier by Rafael Elul, an Israeli scientist who had taken a leave of absence from the Hebrew University-Hadassah Medical School, in Jerusalem, to work at the Brain Research Institute, Adey had learned that tiny, fluid-filled spaces between brain cells contained sugar-tipped strands of protein that protruded from the membranous surfaces of the cells. He also learned that the tips of the protein strands were extremely sensitive to positive and negative currents; they could be seen to sway in response to them.

“At that time, brain waves were widely regarded as being a general ‘noise’ in the cerebral system, and as having little or no direct physiological role in information processing,” Adey recalled recently. “It was also believed that the excitation of nerve cells required powerful electric stimulation in order to overcome the tenth-of-a-volt electrical field that is known to be present at all times between the surface and the interior of every cell membrane. There appeared to be good reason for this, because the electric charge between the exterior and the interior of the very thin cell membranes, which is known as the membrane potential, is enormous. It is, in fact, equal to the charge of a two-hundred-thousand-volt power line if the power line, instead of being suspended fifty feet in the air, as is customary, were to be placed an inch above the ground. In such a case, though, the power line would, of



course, instantly arc over and burn out. That gives some idea of the astonishing resistance to electrical current that is provided by the two layers of fat-together only a millionth of an inch thick-that make up the membrane of a cell. Indeed, the insulating quality of the tiny cell membrane is vastly more efficient than most, and perhaps all, man-made materials. The wonder is that every cell in the body functions from birth to death with this extraordinary electrical barrier at its surface. A major question to be answered, therefore, was how this could be so.

“Elul’s work showed us that the protein strands protruding from cell surfaces might act as Trojan horses to permit extremely weak electrical and chemical signals to pass through the barrier of the membrane potential and reach the cell interior. It paved the way for us to consider the possibility that these strands might be sensitive to electrochemical breezes blowing across the cell membranes- much in the manner of a field of wheat waving in the wind -and to hypothesize that the rhythmic waves they were generating were not just general noise but intercellular

whispering; in other words, the sound of brain cells communicating with each other in a private language. Since all brain waves, whether they are dominant EEG waves or the weak electric ripples emanating from the interiors of cells, travel as oscillations through the fluid-filled spaces-or gutters, as I prefer to call them-it was obviously important for us to know more about what was going on in these gutters. It was also necessary for us to learn more about the role of calcium, whose prevalence in brain tissue had fascinated me since my days as a medical student, and whose ions were known to play important roles in the transmission of nerve impulses in the brain.”

During the middle nineteen-sixties, Ahron Katchalsky, a Russian-born molecular biologist and biophysicist from Israel, who was a member of the Massachusetts Institute of Technology’s Neurosciences Research Program, investigated the binding of calcium, magnesium, hydrogen, and other important biological ions to artificial molecules that simulated the protein strands found in all living tissue. He discovered that calcium ions are bound

more strongly to the protein strands than are most of the other ions present in the fluid-filled gutters of the brain. At about the same time, other scientists demonstrated that calcium might be involved in chemical changes taking place at the membrane surface. At that point, it became clear to Adey that if he was going to learn anything about the role of the cell membrane in brain chemistry he was going to have to investigate the binding and unbinding of calcium. So when the space program began to wind down, in 1970, he decided to pursue this line of inquiry in earnest.

The approach that Adey and his colleagues used in studying cerebral calcium was influenced by a study they had conducted for the government in 1967 and 1968, which, in turn, resulted from the discovery by the State Department, in 1962, that the Russians were beaming low-intensity microwave radiation into the American Embassy in Moscow. At first, it was believed that the microwaves were being directed into the Embassy to activate electronic listening devices hidden in its walls. It was soon realized, how-

ver, that the Russians were transmitting at multiple frequencies that did not appear suitable for normal electronic-avesdropping techniques, and by 1965 the motive for the Soviet microwave bombardment had become the subject of intense scrutiny by various American intelligence agencies, including the Central Intelligence Agency, whose officials suspected that the Russians were conducting research into the effects of microwaves upon human behavior. For security reasons, this scrutiny was carried on with the utmost secrecy, and was cloaked in the usual euphemisms. The microwave beams being directed at the Embassy were referred to as the Moscow Signal; the investigation of them was carried out under a highly classified research program called Project Pandora; and information about it was parcelled out on a strict "need to know" basis, which, as it turned out, excluded most of the State Department employees at the Embassy who were being irradiated. Some idea of what was afoot can, however, be gleaned from the fact that C.I.A. agents interviewed a number of scientists who were involved in microwave research, asking them such questions as whether it was reasonable to believe that microwaves beamed at human beings from a distance could affect the brain and alter behavior.

Project Pandora was placed under the direction of the Advanced Research Projects Agency (ARPA)-an organization within the Department of Defense which was then engaged in developing a wide variety of electromagnetic weaponry. In 1966, ARPA gave a number of research contracts to independent scientists to study the effects of low-level radiation in test animals. Among them was a contract awarded to Adey and some colleagues at the Space Biology Laboratory to investigate the effect of weak ELF electrical fields, oscillating at seven and ten hertz, on the brain waves and the behavior of monkeys. Together with Rochelle J. Gavalas-Medici, an experimental psychologist, and other associates, Adey conducted a series of experiments during which three monkeys in whose brains EEG electrodes had been implanted were trained to press a panel once every five seconds, and were rewarded with apple juice if they performed within a two-and-a-half-second interval. After the animals were per-

forming satisfactorily, they were exposed for four hours a day to very weak, ten-volt-per-metre electric fields oscillating at either seven or ten hertz. Exposure to ten-hertz fields did not produce any marked change in the monkeys' behavior, but when the animals were irradiated with seven-hertz fields their ability to estimate a five-second interval was shortened by as much as half a second. Moreover, Adey and his co-workers observed increases in EEG intensity at both the seven- and the ten-hertz frequencies in the limbic system of the brain in all three monkeys. The increase indicated that the externally applied electric fields could drive the electrical activity of the brain, and thus produce a phenomenon called brain entrainment, which had obvious application for mind control.

During the early nineteen-seventies, Adey, Gavalas-Medici, and Suzanne M. Bawin, a Belgian-born research neurophysiologist, who was doing her Ph.D. work under Gavalas-Medici's supervision, studied the effects of low-intensity electric fields of seven, forty-five, sixty, and seventy-five hertz on the brain waves and behavior of monkeys. Their one consistent finding was that weak fields (some as low as one volt per metre) oscillating at brain-wave frequencies could produce significant changes in the EEG and in behavior. This finding was reinforced when they exposed live cats to very high-frequency (VHF) radio waves, of a hundred and forty-seven million hertz (147 MHz)-a frequency used by ham-radio operators- modulated at brain-wave frequencies. What they did, in effect,



was to impose the slow ELF rhythm of the brain waves on the fast oscillation of the radio waves. They discovered that unmodulated 147 MHz radiation at a field intensity of one milliwatt per square centimetre had no biological effect, but that an ELF-modulated signal of the same intensity could powerfully change the pattern of the cats' brain waves at specific sites within the brain and at specific ELF frequencies. Among other things, this indicated to Adey and his colleagues that radio-frequency fields at power levels far below those necessary to induce the heating of tissue could produce profound changes in the electrical activity of the brain.

In 1974, Bawin, Adey, and Leonard K. Kaczmarek, a newly graduated bio-

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chemist from the Charing Cross and Westminster Hospital Medical School, at the University of London, exposed freshly removed chick brains to the same low-power, ELF-modulated 147 MHz field that had been used in the cat experiments, and found that exposure to specific frequencies between six and twenty hertz increased the release of calcium ions bound to brain-cell membranes and to their protruding protein strands by about twenty per cent, with a maximum effect at sixteen hertz. A graph of the results showed that the outflow of calcium followed a "tuning curve," with the peak of the effect at sixteen hertz and a lower effect at both higher and lower frequencies. (By way of contrast, the unmodulated carrier wave of 147 MHz produced no effect.) Thus Bawin, Kaczmarek, and Adey concluded that the phenomenon did not depend simply upon the intensity of the electromagnetic field but was sensitive to a narrow "window" of frequencies. In later work, Adey and his associates observed similar windowing with respect to a narrow range of field intensities and to lengths of time of exposure.

By the end of 1975, Adey and his co-workers had gathered considerable evidence to show that weak electromagnetic fields have a direct effect on the vertebrate nervous system. Their monkey studies had produced behavioral effects indicating that weak oscillating fields could result in modification of recall and of the ability to estimate time. Their experiments with chick-brain tissue and live cats indicated that weak fields could alter the flow of calcium from the membranous surfaces of cells and from their protruding glycoprotein strands, thus changing the chemistry of the brain. These findings led them to conclude that slow electrical oscillations within the forest of protein strands surrounding brain cells formed the basis of an independent cell-to-cell communication system, and to speculate that such oscillations might be the basis for changes in brain chemistry associated with the storage of information.

What remained unclear was how electromagnetic fields that were less than one four-thousandth the strength of the electric barrier provided by the membrane potential could act as an electrical stimulus capable of influencing the release of calcium and other chemicals from the surfaces of brain

cells. In an attempt to explain the **mystery**, Adey pointed out that, the **membrane** potential notwithstanding, a brain cell is so sensitive to fields that **surround** it that if one terminal of a one-and-a-half-volt battery were **connected** to a wire placed in the Pacific Ocean at San Diego and the other **terminal** to a wire in the Pacific Ocean near Seattle-about a thousand miles away- the cell would be able to detect the infinitesimal electric gradient of the resulting one ten-millionth of a volt per centimetre that would be produced in the intervening seawater. Adey then **postulated** that weak electromagnetic fields must be acting as triggers to stimulate and amplify a powerful system of cooperative interactions at the membrane surface. As for the reason that these electromagnetic fields did not elicit major disruptions of cerebral **processes**, such as producing perceptual distortion or interfering with judgment and decision-making, Adey suggested **that**, because each cell in central-nervous-system tissue generates its own **very** small electric field within its own immediate, tiny environment, an **electric** field originating outside the **nervous** system would be far too crude to disturb the complex intrinsic field within. In a paper written at the end of 1976, he drew an analogy with ocean waves: "Within a cubic meter of water at the ocean surface there are numerous local pressure gradients producing highly complex focal motions. Passage of a large tidal wave through the same region has relatively little effect on the major fluid movements within this small volume."

Up to this point, Adey's research at the Space Biology Laboratory had been financed almost entirely by NASA, ARPA, the National Science Foundation, the Air Force Office of Aerospace Research, and the Office of Naval Research. This circumstance undoubtedly influenced his decision to become a member of the National Academy of Sciences' committee formed in January of 1976 to evaluate the possible biological effects of the ELF electric and magnetic fields that would be generated by the Navy's Project Seafarer. At that time, he did not seem prepared to make a major issue of his opposition to the thermal theory of microwave and radio-frequency injury, which represented the mainstream thinking of the scientific community on the biological effects of non-ionizing radiation. Some

observers note that Adey and his colleagues were just beginning to probe something profoundly revolutionary in the realm of science, and realized that there were many people in positions of authority and responsibility who might be capable of hindering the painstaking program of research they were about to start.

Whatever the case, when Robert Simpson, the attorney for the New York Public Service Commission, who had recruited Becker and Marino, asked Adey to testify about the biological effects of ELF fields at the power-line hearings, he replied that the issue was far too complicated for lawyers to handle, and that he wanted no part of it. He evinced a similar attitude when he was approached by a journalist at a scientific meeting in Boulder, Colorado, in 1975, expressing doubt whether readers would be able to grasp the difference between biological effects and biological hazards, and voicing concern that the great potential of radio-frequency radiation as a tool for studying the electrochemical workings of the brain might go undeveloped if there were too much adverse publicity. Over the next ten years, however, Adey changed his mind, as he came to realize that the ignorance of laymen and the possibility of adverse publicity posed nowhere near as much of a risk to the search for the truth about ELF electromagnetic fields as did the obfuscation of industry, the mendacity of the military, and the corruption of ethics that industrial and military money could purchase from various members of the medical and scientific community.

-PAUL BRODEUR

(This is the first part of a three-part article.)

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