Containing the Costs of the EMF Problem

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The uncertainty surrounding possible health effects of power-frequency electric and magnetic fields (EMFs) is fueling a costly controversy over the safety of high voltage transmission lines, neighborhood power-distribution circuits, home and office wiring, electrical appliances, and office equipment. Mounting public concerns are driven primarily by a number of epidemiological studies that show increased risks of cancer among populations thought to experience unusual patterns of EMF exposure (*1*). Because the scientific evidence on EMF bioeffects is both complicated and contradictory (*2*), regulatory bodies and scientific standard-setting organizations have been unable to reach consensus on prescriptive approaches to EMF risk management. Although scientific opinion varies widely about whether the EMF-cancer connection is real, public apprehension over potential EMF hazards has prompted a host of political, legal, and market reactions. These include delays in power line construction, growing numbers of court filings involving claims of EMF-induced health damage, property value losses along transmission corridors, the introduction of "low-field" consumer and office products, and the growing tendency of utilities to adopt design measures for new power lines that reduce EMF exposure. In this policy forum, I estimate the economic impact of these trends, compare those impacts to what we, as a nation, are spending to better understand EMF risks, and discuss means for improving the way society manages this fractious environmental problem.

EMF Bioeffects

Studies of the biological effects of extremely low frequency electric and magnetic fields on humans, animals, and in vitro preparations now number in the hundreds, and many detailed reviews are available (*3*). A sketch of the more policy-relevant evidence is provided here.

The very existence of biological effects from environmental levels of power-frequency fields has been challenged on theoretical grounds. Some observers argue that the electric fields and currents induced in body tissues by the electric and magnetic fields of external sources such as power lines and hair dryers are negligible compared to those arising from either the endogenous activity of the nervous system or from thermal noise (*4*). Although numerous experimental studies have indeed found no effect of power-frequency fields on many biological end points, a significant number of reports suggest that EMFs at levels comparable to those near transmission lines and many appliances can elicit some biological responses both in vitro and in vivo. Reported in vitro effects include changes in cell signaling (*5*), cell proliferation (*6*), RNA transcription (*7*), and calcium binding and transport (*8*). Effects noted in animals include changes in biological rhythms (*9*), immune function (*10*), and behavior (*11*). A series of double-blind experiments on human volunteers has demonstrated consistent acute effects on heart rate of exposures to fields comparable to those under transmission lines (*12*). The mechanisms for these reported effects are unknown but a number of hypotheses have been advanced that depend on the coherence and spatial uniformity of the induced power-frequency signal to distinguish it from various sources of electrical noise in tissue (*13*).

Whether the mechanisms giving rise to many of the biological effects observed in the laboratory can contribute to adverse health effects such as cancer in humans is unknown. Laboratory studies show that even relatively strong power-frequency fields do not cause breaks in DNA (*14*) although recent laboratory work suggests a possible role for EMFs in cancer promotion (*15*). Large-scale animal studies of the potential of low-level power-frequency magnetic fields to promote cancer are only now getting under way.

Of the scores of epidemiological studies of residential and occupational exposures to power-frequency EMFs completed in the last 15 years, many have reported statistically significant associations between presumed measures of EMF exposure and the risk of some cancers. These include three of eight case-control studies examining the relations between childhood cancer and neighborhood power lines, and over half of the three dozen investigations of cancer incidence among workers in electrically related occupations (*16*). The diseases most often associated with EMF exposure in these studies are leukemia, central nervous system cancer, and male breast cancer. While these observations seem too consistent to be statistical flukes, there are many possible explanations for these results other than that EMFs cause or promote cancer. Possible confounding factors such as air pollutants in the residential studies or organic solvents in the occupational studies were not controlled. Biases in population selection may have arisen from low participation rates in some case-control studies or from the "healthy worker effect" (*17*) in proportionate incidence and mortality studies. Finally, because all studies have been retrospective, estimates of subjects' EMF exposures have been quite uncertain. Most studies have utilized surrogate measures of past EMF exposure such as job title or the configuration of neighborhood power lines. In the few studies in which magnetic fields were measured at the time of the study, risk was more weakly associated with average measured fields than with job title or power line configuration (*18*). These results imply either that EMF exposure is not causally related to cancer risk, that EMF measurements made in the present are worse indicators of past exposure than are job title and power line configuration, or that biologically relevant aspects of EMF exposure are not captured by simple time averaging.

Some epidemiologic studies have reported statistically significant relations between surrogate measures of EMF exposure and the risk of some noncancer health effects including untoward pregnancy outcome and depression. This evidence is somewhat less compelling than that involving cancer, primarily because the number of studies of any given noncancer end point is small and the results are often conflicting (*19*).

One factor that distinguishes power-frequency EMFs from other environmental agents is considerable experimental evidence showing biological effects of fields that are nonmonotonic functions of exposure intensity or that depend on the strength of the local geomagnetic field (*20*). For instance, the studies on human volunteers mentioned above have shown that heart rate becomes depressed in combined 60-Hz electric/magnetic fields of 9 kV/m and 20 μT, but not in combined fields of 6 kV/m and 10 μT or 12 kV/m and 30 μT (*12*). Such phenomena complicate the interpretation of epidemiological studies that, for the most part, have looked only for associations between risk and exposure measures that are monotonic in 60-Hz field strength and exposure duration. The possibility that the effects are nonmonotonic also limits the appeal of "high-dose" animal studies as a means to estimate human risk at much lower levels of exposure. Finally, nonmonotonic effects have serious implications for proposals to mitigate EMF risk,

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because they imply that measures to reduce the strength of EMF exposure could sometimes be counterproductive.

How Large Could EMF Risks Be?

Of all the conceivable health effects of EMF, the epidemiologic evidence is strongest for cancer. Occupational epidemiologic studies report excess risks of cancer death for workers in electrical occupations that average a few chances per 100,000 per year (*16*, *21*). This is a small fraction of the total occupational risk of death in these occupations (*22*) but is well above the threshold at which U.S. regulatory agencies have on occasion acted to reduce occupational risk (*23*). Residential studies of childhood cancer suggest that the excess risk of cancer death associated with living in a house near a distribution line with wiring configured to produce stronger than average magnetic fields is about 5 per 100,000 per year (*18*, *24*). This is comparable to the childhood leukemia risk associated with in utero exposure to diagnostic x-rays (*25*) and the more speculative childhood leukemia risks associated with abstention from breastfeeding (*26*) and first trimester smoking (*27*). Like possible occupational EMF risks, this level of childhood cancer risk, if real, would lie above the threshold for regulatory attention. Nationwide, the numbers of workers and children in groups identified by these studies to be at elevated risk is about 20 million (*28*) so the resulting population impact would be 10^2 to 10^3 deaths per year if EMFs are indeed hazardous. Of course, because of doubts about cancer causality, there is a good chance that the true impact is zero. On the other hand, most of the positive EMF epidemiologic findings were obtained using surrogate exposure measures that presumably dilute measured risks by introducing noise into exposure classification. In addition, some common cancers (for example, female breast) have yet to be epidemiologically examined for an EMF-related association, leaving open the possibility that other populations may be at risk.

Within the EMF scientific community, opinions vary widely about the probability that the EMF-cancer connection is real. Despite its obvious value to risk managers facing urgent EMF policy decisions, the distribution of scientific opinion on the probability that low-level exposure is hazardous has never been formally elicited. Independent scientific organizations charged with radiation protection have been quite vague in expressing their uncertainty about the risk of exposure to low-level EMFs. In its 1987 criteria document on magnetic field effects, for instance, the International Radiation Protection Association (IRPA) concluded that "when current densities less than 10 mA/m^2 are induced in tissues and extracellular fluids, the induction of adverse health effects is unlikely. However, the possibility of some perturbing effects occurring following long-term exposure (to levels under 10 mA/m^2) cannot be excluded" (*29*). Such ambiguous expressions of risk implicitly pass the task of risk assessment to the policy-maker, for whom annual risks smaller than one-in-a-million can be significant. Painful as it may be to elicit, radiation protection bodies have a responsibility to develop quantitative expressions of their collective assessment of EMF risk. This task might be made more palatable by breaking it into parts that would poll scientific opinion on (i) the probability that environmental EMFs are at all harmful and (ii) the magnitude of the EMF hazard, conditional on the existence of a harmful effect.

Economic Impacts

Concerns about EMF health risks are giving rise to significant economic costs to society on several fronts. First, delays, cancellations, and moratoria on new transmission projects are limiting the economic benefits that those projects could provide (*30*). New transmission lines enhance the ability of utilities to trade power and to make fuller use of their cheapest generators. The savings in electricity production costs made possible by a single 500-kV transmission line can be as high as a few hundred million dollars per year, and annual economic benefits may be tens of millions of dollars, net the cost of the line (*31*). New transmission lines also increase the reliability of electrical service by providing redundant routes for electricity supply. Surveys of the residential, commercial, and industrial sectors suggest that people are willing to pay $1 to $10 to avoid a kilowatt-hour of electrical outage (*32*). Because a single new or upgraded transmission line can reduce expected outages associated with a transmission system by as much as 1 million kilowatt-hours per year (*33*), reliability savings can range up to a few million dollars per year per line. The North American Electric Reliability Council reports that utilities plan to add about 12,600 circuit-miles of new transmission line between now and the year 2000 to service new generating plants and demand growth (*34*). Until the transmission siting problem is resolved, transmission-imposed limits on power delivery will exert upward pressure on electricity prices and will increase the frequency of brownouts and extended outages.

Second, the public's desire to avoid EMF exposure is likely to have a negative effect on property values along existing transmission line routes (*35*). There are about 10 million acres of land and 1 million homes in the United States that lie close enough to a transmission line that associated EMF levels on the property exceed typical household background levels. A loss of even 1% in the value of these properties amounts to a market loss of about $1 billion.

Third, court filings involving claims of EMF-induced health damage from power lines, consumer products, and occupational EMF sources are becoming more common (*36*). Because juries are ill-equipped to deal with the complexities of EMF bioeffects evidence, many of the claims brought so far have been settled out of court for undisclosed amounts. Of the few that have gone to trial, the most prominent involved a Texas utility that was cited for routing a transmission line close to a school. Even though the utility had acted in compliance with all state and local laws, the jury assessed the utility $25 million in punitive damages (*37*). While this judgment was eventually overturned, such suits can be expected to encourage electric utilities, equipment manufacturers, and employers to consider EMF exposure reduction as a means to limit their liability exposure. The future extent of this activity depends on the outcome of a number of toxic tort, product liability, and occupational illness cases that are now in the pipeline.

Fourth, whether to avert litigation, avoid future retrofits, or exercise prudence with respect to public health, many utilities are changing their design practice for new distribution and transmission circuits, placing more of these lines underground, on higher poles, or in more compact configurations. The costs of these measures range from a few percent up to perhaps 30% of the construction cost of these lines. Given that utilities nationwide invest about $13 billion annually in transmission and distribution construction (*38*), the cost of these exposure-reduction practices could well exceed $1 billion per year if widely adopted (*39*).

Fifth, with growing frequency public and business officials are taking measures to reduce EMF exposures in situations involving existing EMF "hot spots." Recent examples include a town that moved several blocks of distribution line underground at a cost of $20,000 per exposed person; a utility that rerouted an existing transmission line around a school at a cost of $8.6 million; a new office complex that incorporated EMF exposure reduction in its design at a cost of $100 to $200 per worker; and a number of firms that have installed ferrous shielding on office walls and floors to reduce magnetic field exposures from nearby power handling equipment at costs ranging up to $400 per square meter of office space (*40*).

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Finally, to reduce liability risk and enhance marketability, manufacturers of some consumer and office appliances have begun to offer "low-field" products at prices that are somewhat higher than older models. Both the $2-billion market in video display terminals and the $100-million market in electric blankets are expected to deal only in low-field models within a few years.

Although it is difficult to assess the economic impacts of the EMF problem with much accuracy, it seems likely that the total economic cost of the activities described above now exceed $1 billion annually, with the promise of growing costs in the years to come. Whether any of these ad hoc responses to EMF risk are worth their price depends on the health benefits that they produce. Currently uncertain, these health benefits can become better known only through additional bioeffects research.

It is instructive to compare these ad hoc expenditures to reduce EMF exposure with the expenditures that might be justified under a cost-benefit paradigm if risks proved to be as large as suggested by some epidemiologic evidence (that is, 20 million people running an excess risk of cancer death of a few chances in 10^5 per year). Studies of risk valuation suggest that the value that people place on reducing small risks differs widely from person to person, from risk to risk, and across different valuation techniques. Across a range of studies, the distribution of willingness-to-pay for risk reductions of one-in-a-million is roughly lognormal with a median of about $3 and a standard deviation of a factor of 2 (*41*). If we were to value the reduction of a unit of EMF risk at comparable levels, the most that we could justify spending on EMF mitigation would be something in the neighborhood of $10 billion per year. This may not be much more than the costs of our current ad hoc efforts and, if applied entirely to the electric power system, would increase electricity costs by only several percent.

The Value of EMF Bioeffects Research

What should we be willing to invest in future research on EMF risk? Consider the possible outcomes. If additional research leads to scientific consensus that EMF risks are significant, a variety of policy instruments could be used to promote mitigation measures that would balance mitigation costs and health benefits at the margin. This would assure that net benefits are maximized. Under this scenario, the value of additional research on EMF risk could be as small as zero if it turns out that EMF risks are, by chance, already optimally managed. If, as seems more likely, our current ad hoc efforts to modify exposure are neither aimed at the best targets nor set at optimum levels, the value of additional EMF research could be as large as the combined economic and health costs that we currently shoulder.

If, on the other hand, additional research leads to scientific consensus that EMF risks are much smaller than suggested by existing epidemiology, then society could conceivably save much of what we now spend to hedge against the possibility that EMFs are harmful. In this case, the value of additional EMF research could be as high as $1 billion per year, equal to the economic costs that we could then avert.

Programmatic research on the biological effects of extremely low frequency electric and magnetic fields has been under way in the United States since the mid-1970s. Currently, about $20 million per year in public and private resources are committed to epidemiological and laboratory research on the bioeffects of power-frequency fields (*42*). Last May, the U.S. House of Representatives passed legislation that would roughly double the federal involvement in EMF research from its current annual level of about $7 million in fiscal year 1992 (*43*). In light of the above analysis, however, even such an expanded budget seems incommensurate with the stakes of the EMF problem.

Although there are many uncertain environmental risks for which the value of information exceeds the federal research commitment, the need for a stronger federal program of EMF research is particularly acute. To its credit, the electric utility industry has historically been the largest sponsor of EMF research. The conflict-of-interest inherent in utility-supported health effects research, however, reduces the chance that the public will find these efforts admissible. This is particularly true for potentially significant negative findings that might, for instance, solve the mysteries of the residential and occupational cancer studies by identifying a non-EMF cause. To allay these concerns, the utility-sponsored effort needs to be complemented by a larger federal program.

Arguments that increases in EMF bioeffects research are justified on value-of-information grounds assume both that further research will reduce scientific uncertainty and that society's response to new information will serve to lower the social cost of the EMF problem by an amount that equals or exceeds the research investment. Realistically, however, any increases in EMF bioeffects research should be tempered by several considerations. First, the research community has a limited capacity to absorb additional support and still maintain standards of quality control. Second, there is no guarantee that additional research will eventually lead to scientific consensus about the magnitude of EMF risk. As the continuing scientific debates over the cancer risk of low-level exposures to ionizing radiation and carcinogenic chemicals show, scientific tools are often too blunt to demonstrate with reasonable certainty that a risk is negligible. Because the costs may be boundless for demonstrating that the risk of a truly innocuous agent lies below society's threshold of concern, some observers have suggested that risk-focused research be undertaken only under well-defined conditions that would halt research when a program reaches a point of diminishing returns (*44*). Finally, even if future rounds of bioeffects research dramatically reduce scientific uncertainty, the public's growing distrust of risk management institutions may limit the extent to which that information can be marshalled to reduce the social costs of the EMF problem.

Some of those who believe that EMF risks are insignificant argue that additional federally sponsored EMF bioeffects research will only serve to legitimize the public's fears and generate just enough false positive results to keep those fears alive in perpetuity. They conclude that federal money would be better spent on communications programs to quell "irrational" public concerns. Without broad scientific consensus that EMF risks are negligible, however, political support for such a strategy is unlikely to emerge.

Improving Risk Management

By itself, more bioeffects research will not solve the EMF problem. We also need a raft of engineering, economic, social science, political science, and legal research to enlighten the process of EMF risk management.

Should future EMF bioeffects research lead to scientific consensus that EMF risks are not negligible, the political pressure to mitigate exposures could be immense. Some analysts have argued that we should prepare now for such a contingency by evaluating the technical feasibility, cost, and effectiveness of alternative means to modify exposures from power lines, home wiring, appliances, and other sources (*45*). Exposure control measures include technical means such as shielding and arranging wires to promote the mutual cancellation of fields as well as behavioral means aimed at keeping people away from sources (*46*). Energy conservation and demand-side management can reduce current loads on existing power lines and delay the need for new

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power lines. The Electric Power Research Institute, the U.S. Department of Energy, and New York State have earmarked a portion of their EMF research budgets for an evaluation of alternative mitigation schemes.

Like other environmental issues, the EMF problem is as much about sociopolitical and ethical concerns as it is about health risk (*47*). It is sociopolitical because the EMF problem pits property owners, workers, and consumers concerned about exposure to risks against large organizations such as electric utilities, government agencies, and manufacturers. It is ethical because the EMF problem involves balancing individuals' desire to be free from involuntarily imposed risks (however small) against society's need to have reliable electric power and electric products at an affordable price. To enhance the utility of the information gained by expanded bioeffects and engineering research, we need a complementary program of social science research that would, for example, assess people's willingness to pay to avoid EMF exposure; devise ways to incorporate the public's values into EMF risk management decisions made on its behalf; articulate the moral basis for imposing involuntary risk such as that born by persons along new transmission corridors; and evaluate the potential of techniques such as property buyouts (*48*), property value guarantees, siting auctions (*49*), exposure taxes (*50*), citizen panels (*51*), and negotiation for resolving conflicts over power line siting (*52*).

To reduce the chance that their decisions will incite more divisive debate, risk managers need a better understanding of the public's attitudes toward EMF risks and risk management. Public perception research performed to date has shown, for instance, that people are much less concerned about EMF risks from appliances than they are about EMF risks from transmission lines (*53*). This notion suggests that the public is likely to demand that transmission line emissions be regulated before those from appliances, even though the latter probably make a much larger contribution to overall exposure. Other research is beginning to yield information on what kinds of risk management actions people consider to be fair and affordable (*54*).

It is too early to predict the extent to which EMF litigation will influence the prices of electricity and electrical products or will affect the viability of industries whose products are associated with either strong or extended EMF exposure. One way to control these costs and avoid a torrent of socially inefficient litigation is to place statutory constraints on the kinds of tort actions that are permitted to include punitive damages, allowing such claims, for instance, only in cases involving EMF exposures that occurred after evidence linking 60-Hz magnetic field exposure with possible health risks became widely known (*45*).

Finally, for risk management to operate fairly, stakeholders should be well informed. Unfortunately, the complexity of the EMF bioeffects evidence makes public understanding of this issue particularly vulnerable to selective reporting, a feature that has been exploited by interest groups on both sides of the EMF debate. Much work is needed to understand the information needs of various groups and to develop channels to address those needs. Recent initiatives by the U.S. Department of Energy, the U.S. Environmental Protection Agency, the State of California, and the utility industry are moving in the right direction.

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