1. Introduction and Overview

Electric and magnetic fields produced by electric power systems have recently been added to the list of environmental agents that are a potential threat to public health. This paper describes peoples' exposures to fields from power systems and other sources (Section **2),** reviews existing scientific evidence on the biological effects of these fields (Sections 3 through 7), presents a history of research support and of regulatory activity (Sections 8 and 9), and discusses problems and alternatives in regulatory action (Section 1 O).

The electric power that is used in our homes, offices and factories uses AC or alternating current. This is in contrast to the DC or direct current that is produced by batteries. An alternating current does not flow steadily in one direction. It alternates back and forth. The power used in North America alternates back and forth 60 times each second. This is called 60 hertz (Hz) power. In Europe and some other parts of the world the frequency of electric power is 50 hertz rather than 60 Hz.

There are electric and magnetic fields wherever there is electric power. This means that there are fields associated with large and small powerlines, wiring and lighting in homes and places of work, and all electrical appliances. These fields are created by the electric charges that are pumped into the power system by electric power generating stations. Electric fields arise from the amount of that charge and magnetic fields result from the motion of that charge. Taken together, these fields are often referred to as electromagnetic fields. The electric and magnetic fields created by power systems oscillate with the current. That is why fields around power systems are called power-frequency or 60 hertz fields. A more complete description of the electromagnetic fields from power systems is presented in Section 2.

Public concerns about power-frequency fields first emerged in the late 1960s as power companies turned increasingly to extra high voltage (EHV) transmission lines to handle large increases in electricity use. EHV lines carry electric power with lower energy losses and with smaller land usage than multiple lower-voltage lines with the same power-delivery capacity. Public attention to EHV transmission lines focused first on the aesthetic impact of their large towers, on the aesthetic and ecological impacts of their rights-of-way, and on various nuisance effects created by their strong electric fields. These nuisance effects include audible noise, TV/radio interference, and induced shocks that can occur when a person standing beneath an EHV line touches **a** large ungrounded metal object such as a truck or farm vehicle. By the early 1970s, the American National Standards Institute had issued voluntary standards to address nuisance effects. The first evidence that power-frequency fields might have a direct effect on human health appeared in 1972 when Soviet investigators reported that workers in Soviet EHV switchyards suffered from a number of nonspecific ailments [Korobkova 72]. Although these reports were greeted with much skepticism by western scientists, they served to stimulate public concern. By the mid-seventies, health effects had become a central issue in transmission line siting hearings in several states.

There are two reasons why conventional wisdom has until recently held that the fields associated with power systems could pose no threat to human health. First, there is no significant transfer of energy from power-frequency fields to biological systems. Unlike X-rays (i.e. ionizing radiation), power-frequency fields do not break chemical bonds. Unlike microwaves (i.e. non-ionizing radiation), power-frequency fields cannot cause significant tissue heating. Second, all cells in the body maintain large natural electric fields across their outer membranes. These naturally occurring fields are at least 100 times more intense than those that can be induced by exposure to common power-frequency fields.

However, despite the low energy of power-frequency fields and the very small perturbations that they make to the natural fields within the body, studies over the last fifteen years have demonstrated unequivocally that under certain circumstances, the membranes of cells can be sensitive to even fairly weak externally imposed low frequency electromagnetic fields. Extremely small signal changes can trigger major biochemical responses critical to the functioning of the cell [Adey 81, Adey 84, Adey 87]. This should perhaps have come as no surprise, as cells, especially those in the nervous system, make use of complex electrochemical processes in their normal function. The ability of some animals including eels, sharks, and pigeons to detect extremely weak ELF fields and use them for homing and finding prey clearly demonstrates that at least some specialized cells can be exquisitively sensitive to such fields. [Fessard 74, Gould 82]. Among the responses demonstrated in laboratory studies using animal cells and tissue are:

- modulation of ion flows;
- interference with DNA synthesis and RNA transcription;
- interaction with the response of normal cells to various agents and biochemical such as hormones, neurotransmitters, and growth factors;
- interaction with the biochemical kinetics of cancer cells.

Even when effects are demonstrated consistently on the cellular level in laboratory experiments, it is hard to predict whether and how they will affect the whole organism. Processes at the individual cell level are integrated through complex mechanisms in the animal. When a process in the cell is lightly perturbed by an external agent such as an ELF field, other processes may compensate for it so that there is no overall disturbance to the organism. Some perturbations may be within the ranges of disturbances that a system can experience and still function properly. This difficulty in extrapolating cellular level effects to predict the existence or severity of possible public health effects, together with the absence of any large-scale and obvious public health effect associated with electrification, are two arguments advanced during the last decade in support of the claim that there is no need for concern about possible public health effects from exposure to power-frequency fields.

Another problem in deducing possible health effects from cellular level effects has been the lack of a theoretical model to explain and understand the detailed mechanism of interaction. ELF fields affect the cell via the cell membrane. Cell membrane biology is still in its infancy although this area of molecular biology has made great strides in the past few years. Until recently, there was not enough understanding to even advance hypotheses on the potential mechanisms by which ELF fields may cause significant perturbations in cell and organ functions. Hypotheses are now being advanced but are still at a speculative stage [Adey 86, Smith 87, Liboff 86].

As we discuss in Section 3, findings at the cellular level display considerable complexity including resonant responses (or, “windows”) in frequency and field strength, complex time dependencies, and dependence on the ambient DC magnetic field created by the earth. For these reasons, ELF fields appear to be an agent to which there is no known analog. Many lessons learned from environmental hazards such as chemical agents (PCB, vinyl chloride, benzene, etc.) or physical agents (ionizing radiation, asbestos etc.) may not directly apply to ELF fields. This is because in the case of fields it is not yet clear what measures of exposure or “dose” are relevant. In contrast to more familiar environmental agents where “if some of it is bad, more of it is worse”, it may not be safe to assume that if ELF field

exposure leads to health risks, exposure to stronger fields or exposure for longer periods is worse than exposure to weaker fields or brief periods.

In addition to cellular studies, whole animal and human experiments have examined five general categories of effects:

1. General effects such as detection, avoidance and behavior response and development and learning of animals, and moods of humans;
2. Effects on externally measured physical parameters such as growth and birthweight, respiration, heartbeat rate, and temperature rhythms;
3. Effects on specific biochemical such as hormones that are responsible for the maintenance, regulation and control of general physiological and psychological functions ; for response to environmental stressors; for growth and development; and, for triggering special responses such as sexual function, and fetal and newborn nourishment;
4. Effects on circadian rhythms of animals and humans; and,
5. Effects in the epidemiology of cancer, particularly leukemia and brain cancer.

Several authors and scientific advisory panels have reviewed the effects literature. [Adey 86, Adey 87, AIBS 85, Carstensen 87, Florida 85, Grandolfo 86, Lee 86, NYSPLP 87, Sheppard 83, West 86, WHO 84]. In summary, the results are complex and inconclusive. There have been many “negative” experiments, that is, experiments that have looked for effects but not found any difference between biological systems that have been exposed to fields and those that have not. However, the growing number of positive findings have now clearly demonstrated that under specific circumstances even weak low-frequency electromagnetic fields can produce substantial changes at the cellular level, and in a few experimental settings, effects have also been demonstrated at the level of the whole animal. Epidemiological evidence, while controversial and subject to a variety of criticisms, is beginning to provide a basis for concern about risks from chronic exposure. Some observers find this epidemiological evidence more persuasive in light of the clear evidence of effects that is available at the cellular level, but others insist on treating the evidence from these two areas as separate.

As recently as a few years ago, scientists were making categorical statements that on the basis of all available evidence there are no health risks from human exposure to power-frequency fields. In our view, the emerging evidence no longer allows one to categorically assert that there are no risks. But it does not provide a basis for asserting that there is a significant risk.

If exposure to fields does turn out to pose a health risk, it is unlikely that high voltage transmission lines will be the only sources of concern. Power-frequency fields are also produced by distribution lines, wall wiring, appliances, and lighting fixtures. These non-transmission sources are much more common than transmission lines and could play a far greater role than transmission lines in any public health problem.