Extremely low frequency electric and magnetic fields: it is time to be reasonable

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"Chance favors the prepared mind." Louis Pasteur

Asbestos, bovine spongiform encephalitis, diethylstilbestrol prescribed to pregnant women, human growth hormone, all of these public health crises have contributed to the emergence of the precautionary principle. Should the electromagnetic fields (EMF) produced by electric current at a frequency of 50-60 Hz be added to this list?

The first questions date back to the 1960s with Asanova's study [1] of workers and then to 1973, when Young [2] published *Power Over People*, mentioning the "*electrochemical oxidants produced by the corona effect.*" But it was not until 1979 that an epidemiologic study resulted in launching an exemplary public health process that combined epidemiologic and biological research to assess the reality of a possible risk. Given a product as ubiquitous as electricity, the stakes were high.

The accusation of danger was summarized by Paul Brodeur in two books: *Currents of Death* and *The Great Power-Line Cover-Up: How the Utilities and the Government are Trying to Hide the Cancer Hazard Posed by Electromagnetic Fields*. Are low frequency EMF the source of an invisible but omnipresent threat? Have we ignored, or, worse, hidden a fearsome carcinogen? After 30 years and several thousand scientific publications, it is time to review all the evidence.

Origin of the alert

When epidemiology demonstrated causal relations between smoking and lung cancer, between asbestos and pleural mesothelioma, between hepatitis B virus infection and liver cancer, these alerts came first from clinical observations. These relations were hypotheses that could be tested by epidemiology and its methods, by comparing the exposed and unexposed populations and taking into account as well as possible the risk factors tested and the known confounding factors. At the same time (or later), experiments provided confirmation of the risk and, in the best cases, an explanatory mechanism.

Here, the route was different. It was an exploratory study that suggested that the electric lines near the homes of children with cancer might have increased the probability of these cancers: *"(...) ... why we chose to study power lines and cancer in the first place: the fact is, of course that we didn't. What I originally set out to do was just a bit of "shoe leather" epidemiology, visiting birth homes of young leukemia cases and controls to see what clues of etiology might appear, I wanted to see if cases has lived close to each other, which might suggest an infectious etiology; if they had lived near polluting factories or on busy streets; and so on*" [3].

Some subsequent studies showed consistent results about the risk of leukemia in children at an exposure level on the order of an average of 0.3 to 0.4 µT. The mean level in daily life in Europe is from 0.01 µT to 0.1 µT. But had we really answered the question?

Were the studies really consistent?

Epidemiology, as in any scientific discipline, cannot escape the need for refutability simply because it has its own methodological limitations. The Achilles's heel of epidemiology, and especially of environmental epidemiology, is the precise assessment of exposure. The sources here are multiple (electric lines and substations, railroad lines, home electric cables, etc.). The first studies, lacking a better alternative, assessed exposure indirectly. In the United States, the "wire code" integrated the distance to homes and the cable diameter (correlated

to the intensity of current going through the cable and therefore to the magnetic field). In Europe, the distance between homes and electricity transmission lines was the most frequent criterion used to classify exposure.

These indirect approaches to exposure are still not relevant because they do not reflect the reality of exposure: "*clearly using distance from power lines, without taking account of other variables (. . .) results in a poor proxy of residential magnetic field exposure*" [4].

In the studies where measurements were taken, they were most often limited to the child's room, which is reductive, therefore insufficient: in assuming an indicative value for "residential" measurements, the choice of indicator is in question. To reflect the "dose" received by the organism, it must take into account in particular the time exposure first began, its duration, intensity, and temporal variations. Other limitation: in the absence of a duly demonstrated biological effect allowing a validated choice, there is no single exposure parameter prevailing. The studies have variously used the geometric mean of variable time periods, medians, and arithmetic means. As Wertheimer wrote: "*we don't know what to measure*".

Finally, the question of bias persists. The classification errors between exposed and unexposed populations, selection bias, especially of controls, publication bias, and failure to take confounding factors (which are not always known) into account all contribute to weakening the reach of the results. The concordance of the epidemiologic data therefore does not imply a causal relation: it simply shows a succession of studies using comparable exposure indicators. Nonetheless, do they really reflect the ubiquity of exposures?

In 2002, the International Agency for Research on Cancer (IARC) relied on these findings to classify magnetic field exposure as a possible carcinogen for levels of exposure on the order of or higher than a mean of 0.4 µT [5]. In 2007, the World Health Organization (WHO) indicated that the epidemiologic proof of this effect is *"weak*" [6].

So many different diseases for a single physical agent?

The role of electromagnetic fields has been raised for different types of cancer with different types of mechanisms: leukemia in adults and children, malignant or benign brain tumors, breast cancer, testicular cancer, lymphoma… They have also been mentioned in neurodegenerative diseases with physiopathologies as different as Alzheimer disease and amyotrophic lateral sclerosis. Questions have also been raised, and studies conducted, about cardiovascular diseases, depression and suicide, and fertility disorders. Finally, hypersensitivity to electricity is part of this same list.

A carcinogen with no toxic effect?

Exposure to most chemical or physical agents known to be human carcinogens produces a toxic effect, that is, preliminary chronic irritation (cell damage) before any tumor appears. Chronic smoker's bronchitis can precede the onset of bronchial cancer. Exposure to UV rays accelerates skin aging. Formalin is first a respiratory irritant before it is a carcinogen. Pleural plaques and fibrosis are earlier manifestations of asbestos exposure than pleural mesothelioma.

Exposure to ionizing radiation is another example. The radiation burns due to the handling of radioactive materials occur before the first cases of skin cancer, which develop on the radiation burn sites. Although this point is not valid for every carcinogen, it nonetheless merits attention.

A carcinogen with no harmful effect on animals?

In laboratory rodents, studies of lifetime exposure have not shown either tumor initiation or any effect of food intake, weight, or behavior. These conclusions are validated up to magnetic field levels of 5,000 µT, some 50,000 times higher than that measured in residential areas.

Most studies of tumor promotion report the same findings.

These negative results are important because all the known human carcinogens tested for carcinogenicity in animals in experimental studies have shown positive results in one or several animal species. Moreover, *"… for several physical or chemical agents…. carcinogenicity was established or strongly suspected in experimental animal studies before epidemiologic studies confirmed their carcinogenicity in humans*" [7]. There is currently a consensus about the absence of carcinogenicity in the experimental studies.

No plausible mechanism of action

Besides the induction of current in the human body,[1] no mechanism of action in living creature has been demonstrated. A publication reviewing some 20 candidate mechanisms found none that might interact with living beings below a threshold value of 50 MT [8].

EMF are not mutagenic because the energy delivered to cells ($2.5\ 10^{-13}$ eV) is several billion times less than that of ionizing radiation capable of damaging DNA.

Have Hill's criteria of causality [9] been met?

The strength of the association (relative risk) was around 2 in the first combined analyses. It has fallen in the most recent studies, even as their methodological quality has improved. The improvement of the classification between exposed and unexposed populations, for example, should have resulted in reducing the confidence interval, but that has not been the case. The most recent studies show instead associations that are not statistically significant or no associations at all.

There is no consistent association over all studies, for most show no significant association. The studies taking the variability of exposure into account with an exposimeter have been negative.

Dose-effect relation: one of the most reliable criteria of causality is a gradient relation between the level of exposure and the amplitude of the effect. This relation has not been observed for childhood leukemia. Moreover, the epidemiologic studies in workers exposed to magnetic field levels 10 to 15 times higher throughout their working life have not shown any excess risk.

The exposure must precede the effect: this criterion is met, because the magnetic fields associated with electricity use have been present everywhere for more than a century. Nonetheless, the usual latency between an exposure to a carcinogenic substance and its effect is not present.

The animal experiments studying carcinogenesis have proved negative.

Finally, in terms of biological plausibility, no mechanism “squares” with the effect of a magnetic field at these levels of exposure.

After 30 years of work, "*epidemiology stands alone*"[10], but less and less certain.

Has this issue merited the work that has gone into it? Yes, certainly. The responsibility both of electric utilities as an electricity company and of the public authorities required that we ensure the safety of EMF or take measures to reduce exposures.

We have also learned a great deal from this alert: never to neglect signals that might foretell a public health crisis, to provide resources to independent research, and promote the use of multidisciplinary expert advisory groups so that we are never right all alone.

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[1] It is on the basis of such an effect that guidelines for the exposure of workers and the general public were issued, but it is simply not relevant in terms of a potential mechanism of carcinogenesis.

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