. . . unseen, unheard, unfelt, but toxic?

Electromagnetic Fields: Biological and Clinical Aspects

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Our entire biosphere is immersed in a sea of man-made electromagnetic fields (EMF). Occupational and public health data suggest that these fields may be a health hazard, possibly involving cancer and fetal loss. This paper reviews the history and pertinent physics of electromagnetic fields and presents evidence from the authors' work, and that of others, of biological interaction with living systems. Epidemiological data suggesting EMF hazards are reviewed including a discussion of possible risks associated with Hawaii's Lualualei transmitter site, TV and FM antennas in high-density population areas, fields surrounding electric power transmission and computer terminals, and the plan to route a major highway through the near-field of an operating Omega signal-source. In the face of current public fear and controversial research reports about long-term EMF exposure, suggestions are presented for public policy about these local sources of concern, as well as for the EMF risks common to any similarly developed areas.

"Knowledge is an island surrounded by a sea of mystery"
—Raymo

Mystery, yes, and in our industrial world, a sea of electromagnetic fields. Do these fields matter? Are they a threat to health or longevity of individuals who are exposed to heavy doses and to entire populations who are lightly exposed? Simply stated, at some energy levels, yes, and at others, perhaps; there are more questions than answers, but the answers are fascinating.

Power lines, antenna fields, household appliances, computer terminals and microwave sources are all suspect in a burgeoning literature featuring numerous complaints and diseases, reproductive problems and cancer.

History

In the first millennium BC curious Greeks noted that amber, rubbed with cat-fur attracted feathers and other light, small objects. At about the same time a shepherd named Magnus found that a certain rock attracted the nails in his shoes and the iron tip of his staff. These astute observers had discovered, separately, electrostatic and electromagnetic fields the nature of which today remains nearly as much a mystery as it did then.

In AD 1269, Maricourt, a French crusader, mapped out the magnetic field around a lodestone sphere, describing poles and lines of force. By 1663, many healers had exploited magnetism for imagined medical uses; to this day, hopeful believers wear magnetic rings, bracelets, or chains, and sleep on magnetic mattresses.

Although known in the middle ages, fields of static electricity have never elicited popular interest; however, it is becoming politically and environmentally a concern of power companies operating very high-voltage, direct-current, transmission lines.

Although Newton and Huygens in the 1600's developed a primitive understanding of electromagnetic waves in studying the physics of visible light, it was not until Helmholz, in 1894, predicted that the radio-waves discovered by Hertz in 1887 would be time-varying, electromagnetic fields, which, in expanding at the velocity of light, combine an electrical force (known as the E field) with a magnetic force (known as the H field) at right angles in a manner characteristic of the entire electromagnetic spectrum from gamma radiation through X-rays, light, microwaves, and the very "longest" radio-emanations (Fig. 1). To learn the full biological significance of

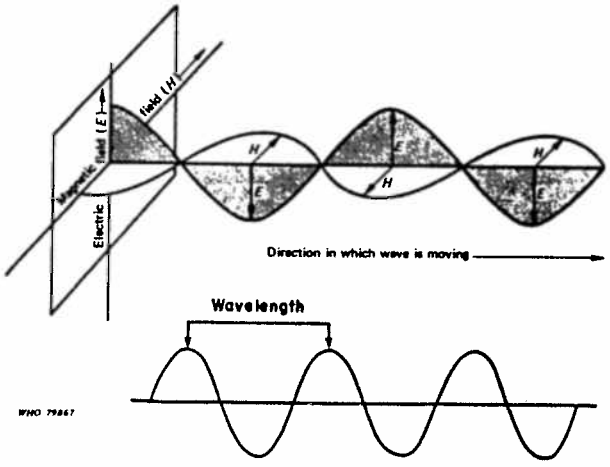

Fig. 1: An electromagnetic monochromatic wave. Electromagnetic waves consist of electrical and magnetic forces which move in consistent wave-like patterns at right angles to one another.

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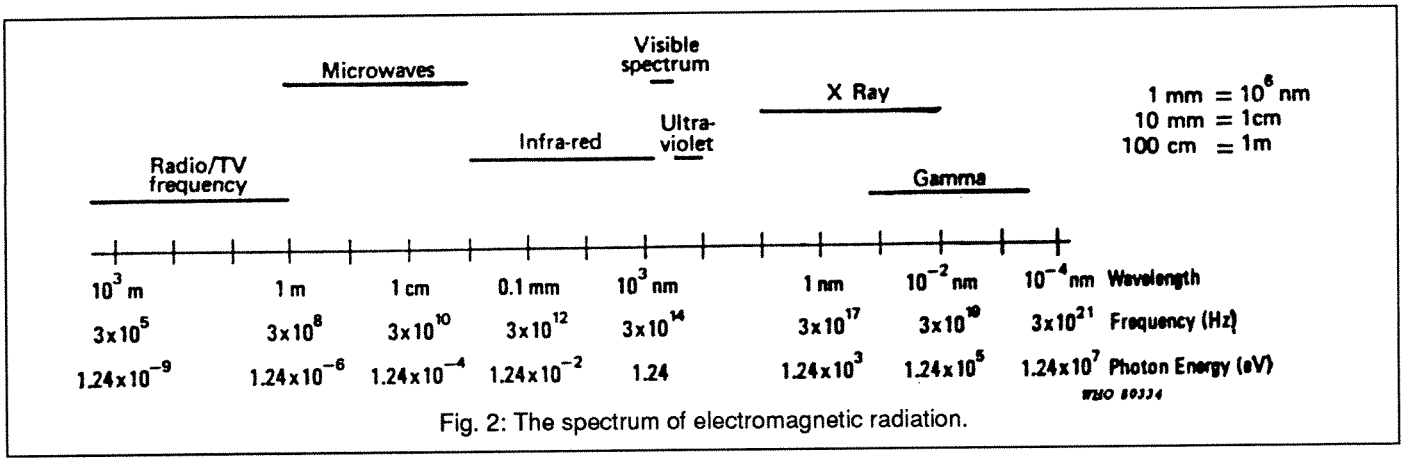

Fig. 2: The spectrum of electromagnetic radiation.

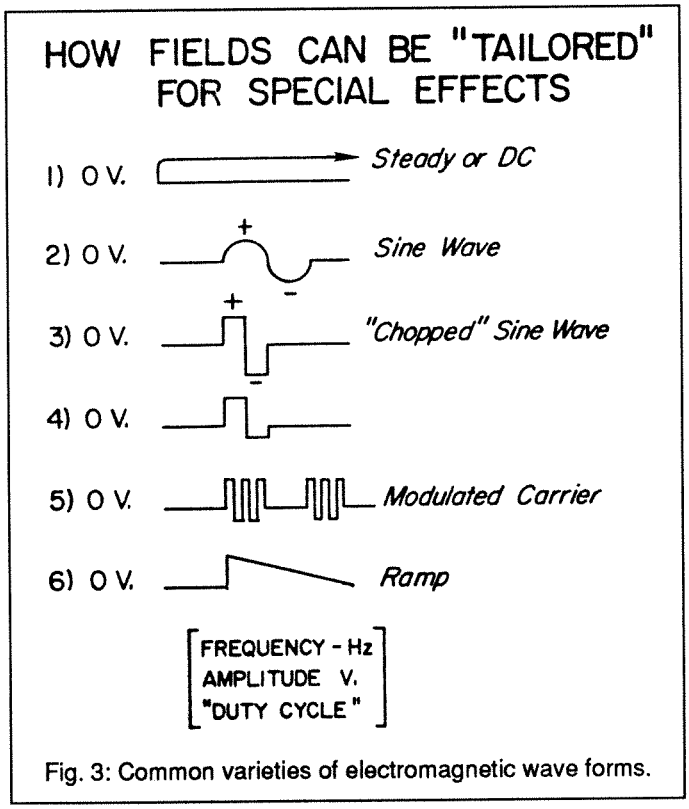

Fig. 3: Common varieties of electromagnetic wave forms.

exposure to these extremely low-frequency (ELF) fields is indeed urgent. How do these energy fields interact with living things, do they always, and how do we know?

Some Physics

Electromagnetic output at all frequencies and wavelengths exhibits both wave-like and particle-stream behavior. The particles are known as photons, and the energy they carry varies tremendously with the oscillation frequency of their source (Fig. 2). Photons of the very high-frequency, ionizing, gamma rays are biologically highly destructive; those of ultraviolet light, are somewhat less so, and equally so are the wavelengths as we go down through the frequency range. We finally reach energy levels at which obvious biologic effects are primarily thermal.

Critical absorption relatonships exist between wavelength and size of the "illuminated" animal, person, organ, or in heating tissue. Absorption of energy is enormously affected by molecular size at high frequencies. Tissue-heating (Joule-heating) from intense exposure to microwaves cooks our foods, mostly by interaction with water and protein molecules. More gentle heating at the infrared level warms us in cold buildings.

Dosimetry standards and field-measurement techniques in assessing ionizing and Joule-heatng energy have been developed by radiation-physicists and users of microwave technology. Although allowable standards of exposure vary, it is axiomatic that the higher-energy portions of the electromagnetic spectrum can be injurious. American National Standards Institute (ANSI) exposure standards for FM and very-high-frequency (VHF) fields are still "voluntary," using 1982 levels of 1000 microwatts/sq. cm, or 0.4 watts/Kg, in the sense of being guidelines.

What of the remaining non-Joule-heating portion of the electromagnetic spectrum? Is it a threat? Are there unknown mechanisms that disturb our normal biologic functions, living as we do in a fog of photons of intermingled, time-varying, electromagnetic fields? Or could any of this part of the energy spectrum even be therapeutically useful? For years it has been thought that below Joule-heating energy-levels (frequency $>10^8$Hz), there could be no biologic affect. Occasional early reports questioned this dictum, but lacking proper controls and accurate field measurements, most of these data were unconvincing.

How are electrostatic and fields generated? How are they measured; and must they be avoided, except perhaps for therapeutic purposes?

Electrostatic fields do not change their strength or direction. ELF time-varying fields change field strength and/or polarity at an arbitrary rate of less than 10^8Hz. Field-strength usually varies as the sine function (E or H sine-theta in cyclic systems) characteristic of our alternating-current power applications. However, for many specialized uses, field energy patterns may be "clipped," biased, or modulated by amplitude or frequency to produce complex wave-forms which have distinctly different biologic effects (Fig. 3). Specially "tailored" waves are commonly the output of experimental, navigational, or therapeutic medical equipment. In radio, antennas are designed to radiate electrical and magnetic energy equally; in

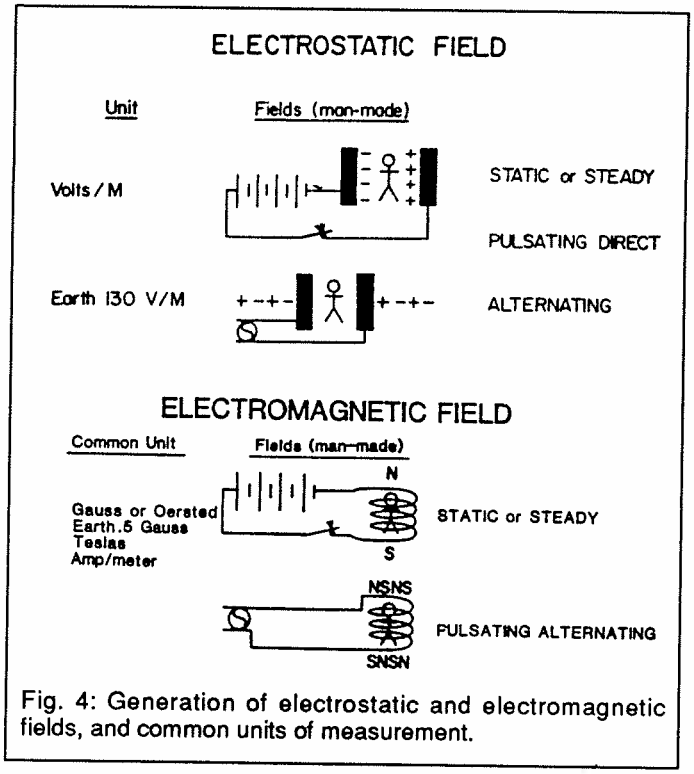

Fig. 4: Generation of electrostatic and electromagnetic fields, and common units of measurement.

experimental uses, the radiating elements are often designed primarily for electrical or magnetic field output, varying according to the use of parallel plates or coils (Fig. 4).

The power of the field is measured in watts/cm^2, the electrical field in volts/m, magnetic fields in amperes/m, or in Teslas, Oersteads, or Gauss (1 T=10^4 G). In the measurement of fields, "near field" and "far field" considerations are important[1]. Complications arise in measuring field-strength when multiple sources are in close proximity, which may produce power overlaps, reinforcements, null-points or other field-discontinuities. Field-strength measring equipment has become sophisticated and relatively convenient. Small, wearable instruments measuring E or H fields are available (Fig. 5). Measurement of the E or H field alone will often permit calculation of the remaining field and the total power involved. Most epidemiologic studies have reported estimated or measured magnetic fields in milligauss, and exposure-site power-levels in milliwatts/cm^2. Many of these units are interchangeable; a most useful term is the specific absorption rate (SAR), which is related to the intensity of the induced internal electric field, and is the energy-absorption per unit mass of an exposed subject — usually expressed in watts/kg or milliwatts/g. The SAR of a body varies widely with changes in frequency or wavelength and is maximal at resonance-frequency[2].

Some Biology

What do we really know about the effects of ELF electromagnetic-field exposure? Reports vary from no measurable effects to teratogenesis and the possible promotion of cancer. In exposure in the field, one must distinguish between interaction, sensation, effect and hazard[3]. It is wrong to dismiss the

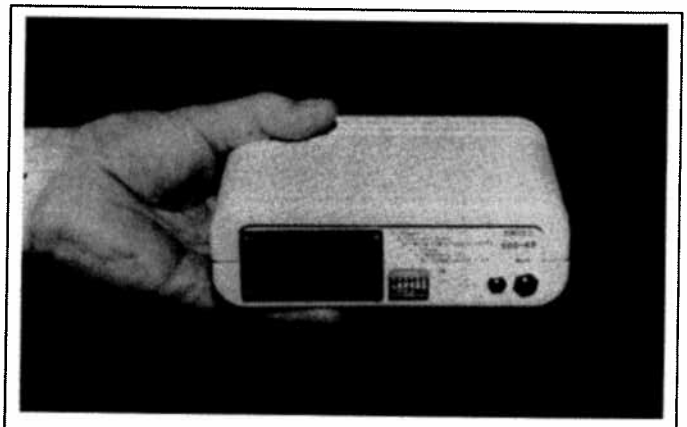

Fig. 5: EMDEX portable field measuring instrument.

possibility of an ELF field-effect simply because quantum energy levels of photons at these frequencies are vanishingly small. Nearly all the energy absorbed by biosystems is by inductive and capacitative coupling, and sometimes by conduction. There is probably some interaction, although it may be only a small change in a dynamic system. "Effect" connotes a physiological perturbation, possibly measurable. "Sensation" is awareness of a physiological change. "Hazard" is less clear — it is essentially a value-judgement, based largely on one's statistical comfort-level. To some, any level of interaction would be deemed hazardous, and so it is with sensation and physiologic changes, although not even measurable change in systems-function is necessarily dangerous — hence the uncertainty surrounding electromagnetic field data, and the difficulty in interpretation of the results of research.

In our experiments in which we have exposed animals, cell cultures and human volunteers to specifically tailored EMF fields, we found distinct growth changes in Tetrahymena[4], and in transplanted neuroblastoma in mice[5]. We also noted reduction in (Na^+K^+)-ATPase activity in mouse-kidney cortex, diaphragm and in liver, as well as in transplanted cells of neuroblastoma[6].

Of clinical significance was the demonstration of localized bone density changes in osteoporotic-prone women exposed intermittently to pulsating magnetic fields for a period of 12 weeks[7]. Others have found field-induced changes in biologic function in bacteria[8], plants[9], animals[10], fish[11], and humans[12]. They have recently described modulation of gene-expression[13], alteration in transcription patterns in dipteran and human cells[14], and changes in protein synthesis in several animal species. Specific frequencies and wave-forms appear to have specific effects[15], and definite frequency- and field-intensity windows exist[16].

Understanding of these phenomena at the molecular level is meager, but theories of interaction include pertubation of transfer of ions through cell-wall and organelle-membranes, cyclotron resonance of certain ions, and reorientation with "pearl chaining" of large molecules within strong electromagnetic fields.

Epidemiologically, evidence of harmful ELF field-interaction is marginal. Suspicion of hazard dates back to the now well-popularized[17] work of Wertheimer and Leeper who, in

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1979, noted that Denver, Colorado children with cancer were 2 to 3 times more likely to have lived near high-current power lines in fields of 4 to 35 milligauss than were their controls[18]. Fulton et al in similar Rhode Island study[19] found no correlation between reported leukemia (the only cancer studied) and power-line configuration. The Electric Power Research Institute (EPRI) evaluated both studies and reported that the conclusions of each were unclear, but that there remained an unexplained correlation in the Dever data[20]. Milham, in 1982, first reported that men in 10 "electric" occupations (electricians, linemen, movie projectionists, streetcar motormen, and others) had excess death-rates from leukemia[21]. Similar work by others was combined with the Milham data by Savitz and Calle in 1987[22]. The results of these 11 studies showed a statistically significant 1.2 to 1.5 times relative risk for developing various leukemias. Telegraph, radio and radar operators, power and phone linemen and electrical engineers showed the most consistent positive results. Similarly, Coleman and Beral[23], reviewing recent work, conclude that electrical workers have an 18% increase in leukemia risk. In evaluating these reports, 3 points are critical — the ratio of reported cancer cases to expected cases is marginal; actual exposure-times and field-strengths are uncertain; and many possibly confounding factors have scarcely been addressed.

In our study, summaries of 14 recent formal statements about the risks of environmental ELF electromagnetic field exposure have been reviewed. Two of these we quote verbatim; 12 of the 14 are in agreement, whereas 2 draw no conclusions.

American Institute of Biological Sciences[24]

"ELF" electric and magnetic fields can, at least in some frequency and intensity combinations and under certain circumstances, cause a variety of effects at any of several levels of biological organization of plants and animals or in-vitro preparations. Additional research on coupling of living systems to ELF electric and magnetic fields, on mechanisms of interaction, and on responses of biological materials to such fields will be necessary to gain a more nearly complete understanding of the biological significance, if any, of interactions of these fields with living systems.

World Health Organization[25]

"In human exposure to time-varying (magnetic) fields, it seems reasonable to assume that a health-risk assessment can be made on the basis of significant perturbations of biological functions caused by electric currents induced by the fields. Available data suggest that, when current densities less than 10 milliamperes/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 cannot be excluded.

In Hawaii

Fig. 6 presents some perspective of the question of the risk of electrical power systems in inducing childhood cancer by comparing this suspected risk with other common risks of modern life.

What of Hawaii's Lualualei antenna complex (which has been declared innocuous, largely because of its relative isolation)[26], the plethora of transmitting radio and TV antennas in the heart of Honolulu[27] and the controversial highway H3, planned to pass directly over the ground plane of an operating Omega navigation transmitter? These pose questions in terms of health risks that are not easily answered. Each has its own unique answer involving arbitrary standards of safe exposure, differences in wavelength and wave-form. In the case of H3, provision for adequate shielding of the completed highway, proper grounding of equipment and conductive materials during construction, etc, pose more questions than there are answers.

Lualualei, unless one chooses to dispute the 1982 report, appears to demonstrate a quite sufficient distance separating the transmitters from the residents "outs.ide the fence" to insure safe operation under the regulations of ANSI, assuming the guidelines actually provide safe limits. New studies of the Lualualei energy output are now being done by the State and

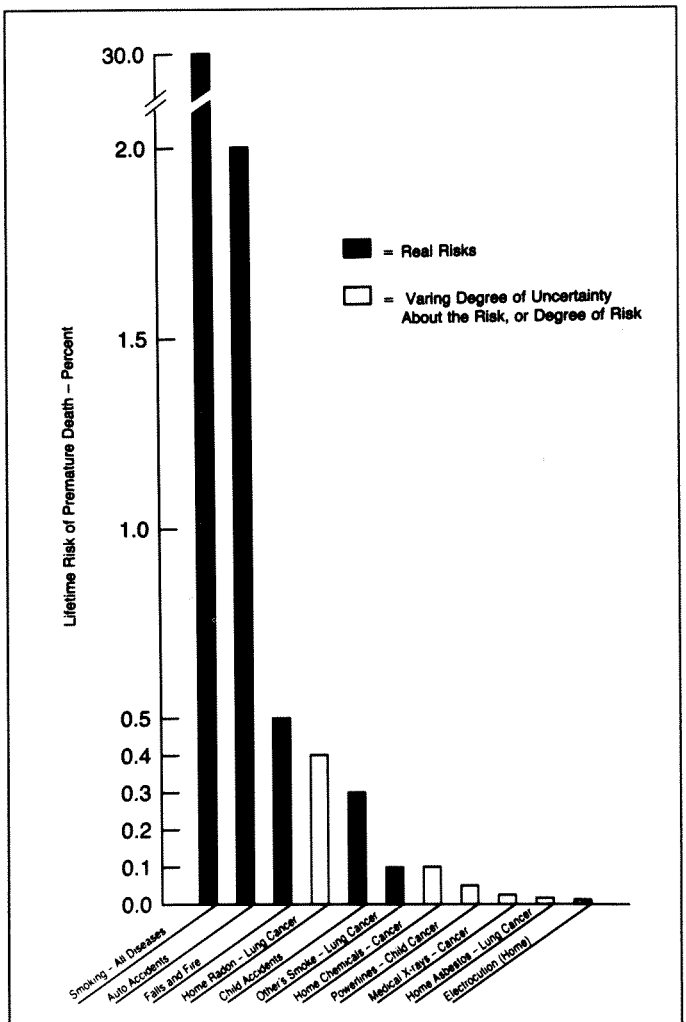

Fig. 6: Lifetime risks of premature death, measured and estimated. (Sources: Nero 1988, Wilson and Crouch, 1987, Ahlbom 1987), from Bonneville Power Adm.

appropriate consultants (1990).

On the other hand, an EPA survey (1984) of Honolulu's commercial radio and TV antennas stated that 2 out of 21 tested locations exceeded the generally accepted exposure-level standard (ANSI = 1000 microwatts/cm^2), but that the exposures would most likely be brief or intermittent, primarily affecting maintenance workers. This suggested that there was little risk to the general population. Again, questions have arisen about the validity of these measurements and of their significance in the absence of certainty about safe exposure limits.

Despite these concerns, a rational effort to avoid causing the public to panic over these 2 issues generated by the State's analysis of exposure should prevail until further research provides contrary data.

Similarly, much better information about the physiological effects of computer-terminal and power-system fields and exposure-levels must become available before dependable conclusions can be drawn about public health issues.

As for the Omega situation in Haiku Valley, building a highway through the near field of the large transmitter also poses an uncertain risk; although the probability may be small, possible, long-term, biologic ill-effects of its complex, modulated, electromagnetic output are simply not certain. They may well be insignificant, aside from simple shock resulting from the high-voltage gradient between the antenna span high overhead between the high mountain ridges that embrace the valley, and the ground. Major assumptions, on which the design of the highway is based, include protection of workers during construction and adequate shielding of the roadway for traffic. Both are represented by the designers of the highway to be feasible and safe and are addressed in their current plans. However, since consultants still disagree on the risks of routing through the antenna system, consideration should be given to relocation of the highway to a new path at least outside the transmitter's circular ground plane.

Large, well designed studies have been launched by the EPRI and agencies with which it has contracts; members of the Bioelectromagnetics Society and the Bioloelectrical Repair and Growth Society, university laboratories, and many foreign researchers are continually exploring the fundamentals of electromagnetic field interactions, as well as their epidemiology, if indeed such exists. Intense worldwide interest by the media and legislative bodies is erupting over EMF issues. While experts are differing over safe exposure levels and health effects, irrationality prevails. Unwarranted conclusions have begun to stifle the development of power systems, inviting poor legislation.

Today's uncertainty about allowable, safe levels of exposure to all sources of electromagnetic energy, with its reluctant possible cancer and fetal loss effects, suggests prudence in the design and placement of new power systems, broadcast facilities, office electronics, and commercial and home electrical equipment in order to best minimize EMF exposure.

One intriguing aspect of our daily total immersion in electromagnetic fields that are currently suspect, is the potential for litigation by persons who have real or imagined field-induced ill-effects therefrom. If some of these cases are won, be they with or without merit, questions of serious economic impact may well arise, affecting power, communications, building, manufacturing and the entire life styles of developed countries.

In today's milieu of uncertain data, public fear and possible economic threat to various electrical activities involving public exposure, several simple steps should be undertaken to meet the problems posed by the interface of current knowledge and political concern:

1. An interested and technically competent advisory group should be formed to assist the State DoH in evaluating EMF issues. These individuals should be encouraged to undertake whatever EMF related research is appropriate and feasible in Hawaii; supportive funding for this effort is essential. Means to establish such a group were begun in June 1990 by State Representative James T. Shon.

2. A State agency should be established and empowered to secure and maintain state-of-the-art field measuring equipment and personnel necessary for its use. Public perception of the credibility of presently available, field-strength data might be improved if confirmed and interpreted by independent investigators who are not owners or operators of EMF sources. Issues such as exposure risks at Lualualei and at Honolulu radio towers might in this way be better addressed by planners and the media.

3. New construction of power systems should be designed to avoid unnecessarily close proximity of electrical power lines and strong magnetic fields to highly populated areas, and public information should advise against prolonged use of computer terminals and the use of electric blankets by pregnant women until more dependable risk-data are available.

4. Most important by far, the many ills of our population such as cancer, the leukemias, reproductive morbidity, mental disease, even social disorder (now being linked to EMF by popular writings), must not be attributed to EMF unless there is absolute proof.

Today our understanding of the effects of ELF electromagnetic fields on biosystems is roughly comparable to what was known of microbiology by Leeuwenhoek in 1687. Within 5 to 10 years, after focused research, at least the core of today's uncertainties will probably be a matter of past history.

Since this article was submitted for publication, the EPA, Office of Research and Development, Washington, DC published a Review Draft which is not "at this stage to be construed to represent Agency policy." It is circulated for comment on its technical accuracy and policy implications, dated October, 1990.

The report is a summary of past and current research. In regard to epidemiologic studies, the report says, "These studies cannot be interpreted as evidence either for or against a causal association between cancer and EM-field exposures."

From the laboratory standpoint, the report continues, "In view of these laboratory studies, there is reason to believe that the findings of carcinogenicity in humans are biologically possible. However, the explanation of which biological processes are involved and the way in which these processes causally relate to each other and to the induction of malignant tumors is not understood."

EPA's final statement says, "This situation indicates the need to continue to evaluate the information from ongoing

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ELECTROMAGNETIC FIELDS *(Continued from page 117)*

studies and to further evaluate the mechanisms of carcinogenic action and the characteristics of exposure that lead to these effects."

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