TECHNICAL PERSPECTIVE #2: FROM SOURCES TO HEALTH EFFECTS: A CONCEPTUAL FRAMEWORK FOR EMF RESEARCH

Paul C. Gailey
Oak Ridge National Laboratory
Oak Ridge, TN

A number of EMF researchers recognized, early on, that the most relevant questions can not be adequately addressed by experts in any single discipline. This problem can be understood best by focusing on the processes required in order for a health effect to occur as a result of EMF exposure. Once this series of events is defined, we can then take a look at the scientific disciplines involved in addressing the various components. The accompanying figure (Figure 1-1) shows the series of events and the disciplines necessary in order to study them effectively.

The sequence begins with a source of electric and/or magnetic fields. Such sources include power lines, ground wires, appliances, transformers, house wiring, and industrial equipment, to name a few. But a source alone is not in itself a problem.

Our next area of concern is exposure. Only when one or more individuals work or live within these source fields do we have EMF exposure. Exposures are complicated by movement through the fields, spatial variations, and all the many possible combinations of exposure parameters.

After exposure, the next step must consider internal fields. We know that internal *magnetic* fields are very nearly the same as external magnetic fields because the magnetic permeability of the body is close to unity. *Electric* fields, however, are a different matter. Electric fields inside the body are reduced by roughly six orders of magnitude from electric fields occurring outside the body. But alternating magnetic fields also induce sizeable electric fields within the body by Faraday induction. In addition, there are endogenous electric fields that may be of comparable magnitude. When all these factors are combined with the extremely complex electric properties of body tissues, we are faced with the difficult problem of understanding internal field exposures: the cells and tissues of the body experience only the internal fields, not the external fields that we can easily measure.

Next, we must address one of the hardest problems in EMF research: how the energy of the fields is transduced into a signal recognized by the biological processes of the body. There are many candidate mechanisms, such as induced membrane potentials, magnetochemical reactions, and magnetite interactions. All of these mechanisms, as well as many others, are known to occur at very high field levels, but the relevance of these interactions at environmentally induced field levels is still a subject of investigation.

Once we change some chemical reaction or membrane interaction, the effect can be important only if it then significantly alters a biological process. Much EMF research has focused on the search for biological effects, but these efforts are hampered by the lack of a clearly defined interaction mechanism and the dose/response relationship corresponding to it. Finally, the biological effect must result in a health effect before we are concerned about it from a risk assessment viewpoint. While nearly everything we do affects our biology (e.g., turning a light on), we only worry about those changes that affect our health (e.g., skin cancer from too much sunbathing).

The study of source fields, exposures, and internal fields falls within the engineering disciplines. EMF engineering studies include source characterization, exposure assessment, calculation of internal fields, instrumentation development, and quality control of laboratory experiments. The EMF RAPID engineering projects have addressed many of these issues.

Both the calculation of internal fields and the investigation of interaction mechanisms fall within the domain of physics. Electromagnetic theory is applied here, along with more fundamental questions of noise, self-organization, nonequilibrium processes, and nonlinear dynamics. Additional problems include characterization of endogenous fields and investigations of information processing within living organisms.

The disciplines of chemistry and biochemistry overlap with physics in the area of signal transduction, but then go on to cover the biological effects step. Signaling within cells is accomplished by highly complex and organized cascades of biochemical interactions. Many of these interactions take place at the cell membrane and involve multiple pathways.

It is important to note here that dose-response can occur at different levels of organization. For example, early consideration of magnetochemical reactions suggested that, while magnetic field amplitude is important, the frequency of the exposure field is not. The reason for this conclusion was that magnetochemical reactions occur on such a short time scale (nanoseconds to microseconds) that time variations in the ELF range would be unimportant. More recently, Eichwald and Walleczek have shown that, if the magnetochemical interaction occurs in an enzyme reaction, the frequency of the magnetic field can actually be very important. Many enzymes cycle at ELF frequencies, and feedback processes within the cycle result in substantial nonlinearities and frequency dependence if one or more steps are affected by an external influence. So, extending our view beyond just the physics and chemistry to the biochemistry, we find a difference between static and alternating field exposures and a possibility of complex frequency response. Should such a magnetochemically sensitive enzyme reaction be identified, it would suggest parallel efforts in engineering to examine whether or not the relevant frequencies occur in the environment.

In considering next to the important discipline of biology, we find that it is necessary to evaluate and interpret the effects of any EMF effects on the development or function of the organism. An understanding of the affected subsystems is critical for evaluating the relevance of any observed effects.

Finally, we must include the disciplines of toxicology and epidemiology. Research in these two areas can provide specific information about the possibility of actual health effects. With limited information, both of these disciplines are relatively blunt instruments for sorting out important parameters. But once clues about relevant dose metrics and dose/responses are discovered, research in these areas can provide very direct information about potential risks.

We are forced to recognize, in summary, that the sequence of events leading to possible health effects of EMF exposure is very complex, and that no one discipline can approach the problem in isolation. An understanding of the relationships of these disciplines to various aspects of the problem is key to unraveling the questions raised by epidemiological and laboratory studies.