TECHNICAL PERSPECTIVE #1
PHYSICAL EXPOSURE PARAMETERS

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Electric and magnetic fields are complex entities, much more so than chemical agents. While exposure to chemicals can often be adequately described by the total amount ingested over some period of time, many more parameters must be considered for fields. Let us examine the most common of these parameters in relation to possible biological or health effects.

Intensity of the magnetic field is everybody's first guess, because it relates directly to the energy of the field. As 'Time Weighted Average' it is virtually the only measure of exposure used by epidemiology. It also tends to be the only parameter in toxicological studies.

Frequency of the field may be equally important. We tend to concentrate on 50 or 60 Hz exposures because these are the nominal frequencies of powerlines. Actually, most sources produce a rich spectrum of frequencies. In particular, the odd harmonics may contain a substantial part of the total intensity. A number of *in-vitro* experiments show resonance-like behavior as the frequency is varied.

Polarization may be important. Kato's investigations of melatonin in rats, for example, seem to indicate that circularly polarized fields yield an effect, while elliptic polarization does not.

Whether biological systems respond directly to magnetic fields or rather to induced currents is a long standing and unresolved question. Magnetic field direction will certainly be important if interactions are due to induced currents, whether in whole animals or in a Petri dish. There are experimental results supporting either the field or the current hypothesis. *In-vitro* biological effects have also been reported from electric fields applied directly.

Dependence on relative direction of the alternating magnetic field with respect to the static earth's magnetic field has also been reported in laboratory experiments, such as Blackman's work on neurite outgrowth.

Because we move through an ever varying electromagnetic environment, the time course of exposure may also be essential. For example, it has been suggested that fields must be constant for some minimum time interval before they can be biologically effective. On the other hand, biological systems may also adapt to a constant stimulus, so that changing field are indeed required to produce an effect. Human experiments on heart rate, for example, indicate that intermittency may be important.

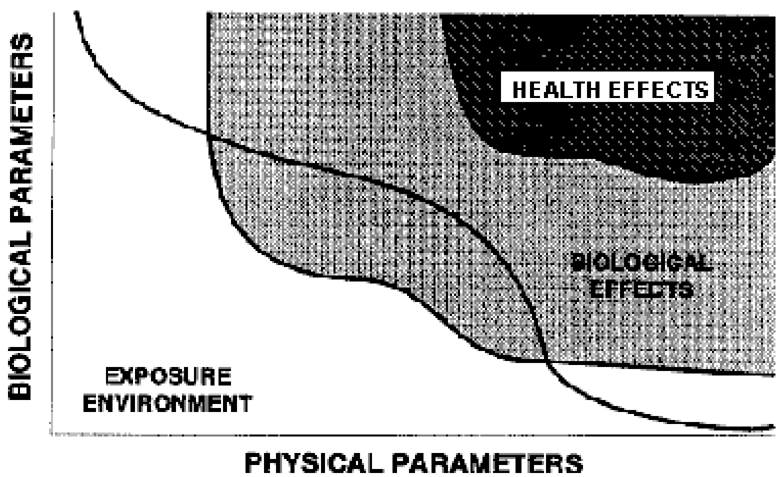
Spikes and transients in field level also need to be considered because they induce large currents. The large body of results on bone growth and wound healing may indicate the effectiveness of spiked signals.

It is sometimes suggested, that biological effects of EMF could be determined by varying exposure parameters systematically. But if we consider only 8 of the exposure parameters, and assume 5 different levels of exposure, we obtain a total of 5^8 or roughly 400,000 different exposure conditions. The search space is immense! Obviously, a "systematic" traverse of parameter space is not feasible. The situation is even more complicated, because we cannot expect the metric to be linear. If it were linear, careful experiments or studies in the vicinity of any set of parameter values would allow us to extrapolate and determine effects for other values. But for non-linear dynamics simple extrapolations may be futile.

Besides the physical parameters of the field, there is also a welter of biological conditions. For *in-vivo* experiments sex, age, circadian rhythm, species and even race are important. For *in-vitro*, we have the cell line, the position in the cell cycle, and the state of activation.

Of course, it must be remembered that interaction between fields and biological systems does not necessarily rely on only a single process. There may be several mechanisms, relying on different parameters or combinations of parameters.

We can make a purely symbolic diagram of the parameter space by lumping all the physical parameters on one axis and all the biological parameters on the other axis. Of course the real parameter space contains a great many dimensions and the variables (sex for example) are not always continuous.

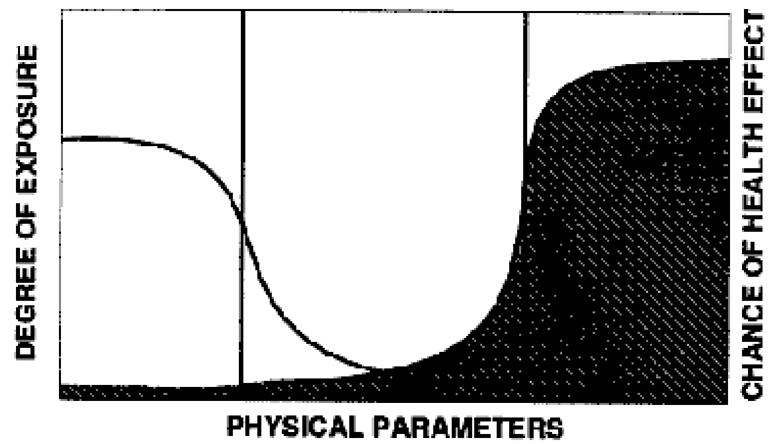


The relationship between exposure, biological effects and health effects can be characterized by three regions of the diagram. The exposure environment identifies the range of parameters we can expect to encounter. This will vary from person to person. Utility line workers will experience much higher intensities, while welders may encounter higher frequencies. In general though, the exposure region will cluster around the origin.

The region of biological effects, on the other hand, will tend to involve higher values of the physical parameters - we know that we can get effects if we make the fields sufficiently 'high'.

Health effects, will form a subset of the biological region. Obviously we must have biological effects before we can have health effects.

To what extent exposure overlaps with biological and health effects is a central question of EMF research.



However, we must remember that the 'boundaries' of the three domains are actually fuzzy regions defined by probabilities. For example, while about 50% of the population has an average magnetic field exposure of 1 mG or less, there are still some 12 million people in the U.S. who are exposed to average fields above 10 mG. Similarly the suggested health effects cannot be expected to set in at some precise level of exposure. Available epidemiology data seem to indicate just this.

We now have a dilemma: At higher exposure levels the risk factors may be greater, but the percentage of people exposed (not their total number!) is quite small. Consequently, the uncertainty will be large. On the other hand, at lower exposure levels the risk factors may become very small, but the exposed population is huge.

In conclusion, we face an immense parameter space. Biological effects, let alone health effects, are small and depend on physical as well as biological parameters in subtle ways. There may be several competing interactions and the resultant metrics can be expected to be non-linear. Obviously, this situation is not likely to be resolved by simplistic epidemiologic or toxicologic studies. What is required is a basic understanding of the underlying biological and physical mechanisms. Meanwhile, it is important to remember, that all metrics, whether wire-codes, spot measurements of magnetic fields, or time weighted averages are surrogates for the actual biologically effective combination of parameters.