PRESENTATION

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Dr. Kavet began his presentation with a general discussion of exposure surrogates, noting that, historically, surrogates often have a negative connotation in the engineering community, which is accustomed to measurements. However, he has come to the conclusion that surrogates are both unavoidable and useful. Material summarizing his presentation has been prepared from the transcripts and his slides. This summary has been reviewed by the presenter for accuracy.

Surrogates

Given that the ultimate interest is in dose and health effects, Kavet defined an EMF surrogate as a measure of exposure/dose that represents the true measure of exposure/dose. As an example, he used the analogy of a bank surveillance camera that captures the "moment of truth" compared to a circumstantial account that "he drove away in a blue car."

It is important to recognize the limitations of surrogates. Surrogates by their nature lead to uncertainty, while observations lead to greater certainty. Furthermore, surrogates in an epidemiology study may establish a link to health outcome, but these same surrogates cannot be used necessarily for exposures in a laboratory study.

Examples of exposure surrogates included measurements (e.g., radiation badges); personnel classification (e.g., job titles); work environment or tasks; behavioral traits (e.g., smoking or appliance use); personal attributes (e.g., age, sex, race); environmental descriptors (residential proximity to traffic or power lines); and biomarkers (nails, hair). Many of these may have a factor associated with them to estimate time and duration of exposure.

He noted that, when using surrogates, there is always a "price to pay" in terms of both study design and efficiency. Affected factors might include study size, cost, effort, quality control, and so on. For example, the quality of the surrogate as measured by its *sensitivity* (the fraction of truly exposed who are classified as exposed), and its *specificity* (the fraction of the truly unexposed classified as unexposed) will directly affect the study size needed to observe a given association at a given level of precision. For a given *power* (the probability of observing a relative risk of a given magnitude and *p*-value), the study size will decrease as the surrogate improves, that is, as the sensitivity and specificity increase.

In response to comments earlier in the symposium, Kavet noted that caution was required in making the blanket assertion that TWA could be considered a surrogate for all other magnetic-field exposures: TWA may correlate with many, but not all, other measures derived from time-series data and it may not be correlated with other field characteristics, such as frequency content, polarization, and transients.

Residential Studies

In discussing residential exposures, Kavet focused on those contributions to exposure other than appliances and transmission lines, which Kaune had discussed. He recognized the Wertheimer-Leeper wire-coding scheme as the landmark surrogate for residential studies. It focused on aspects of proximity and current-carrying capability of the electrical wires external to a house as a surrogate for magnetic field. The Wertheimer-Leeper studies, along with the follow-up childhood cancer study in Denver by Savitz prompted investigations into sources of residential magnetic fields. The EPRI-sponsored 1000-home study was launched to understand magnetic-field sources from an engineering point of view. Results included the finding that power lines and grounding currents were major field sources and that there was a relationship between the measured field and wire code. However, data relating single and duplex homes to wire-code configurations explained only about 14.5% of the variance in the log-transformed magnetic-field measurements.

Kavet and his colleagues have subsequently examined the underground (UG) and very-low-current-configuration (VLCC) homes in the 1000-home data set to better understand the field sources in this low-field referent group. When residences were extracted by specific characteristics (UG and VLCC categories, all single-unit dwellings and duplexes, and none within 500 feet of an overhead transmission line), and a linear regression model used, they found that 28.5% of the variance for the logarithm of spot measurements was due to four factors: net current in the service drop (most important), the number of service drops, the location (suburban or urban), and the age of the home. When a reduced set of homes limited to those with complete ground current and service drop data was examined, a similar model (but without location type) explained 34% of the variance.[1]

To validate the model, they applied it to houses in the ordinary-low-current-configuration (OLCC) category and discovered that the same factors were important in determining magnetic fields. Compared to UG and VLCC houses, OLCC houses tended to have higher ground currents and more service drops, were older, and were more frequently located in urban areas. Kavet expressed the opinion that fields in ordinary-high-current configuration (OHCC) and very-high-current-configuration (VHCC) houses are likely due not to the aforementioned background factors but to currents on nearby overhead lines.

To examine the temporal stability of surrogates, Kavet cited results from the EPRI EMDEX Residential Study, which used a convenience sample of almost 400 residences of utility employee volunteers. It included spot, PE, and long-term measurements, as well as wire-code category in each residence over a series of four visits, seasonally spread over roughly one year. For this data set, Kavet asked two questions: How well do the surrogates at the fourth visit to a house predict exposure at the first visit, and how well does the fourth visit capture the entire year's worth of exposure, as measured during the first three visits? The results in terms of variability explained by each surrogate are shown in Figure 10-1, below, for measurements and wire-code category.

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[1] A paper reporting these results will be available shortly.

Kavet felt that it was pretty clear that the measurements (long-term, spot, and certainly the PE) were superior to wire-code category in explaining the variance from the first visit. Kavet indicated that although other magnetic-field characteristics besides TWA might be of interest in residential exposures, surrogates for them had not been very well developed.

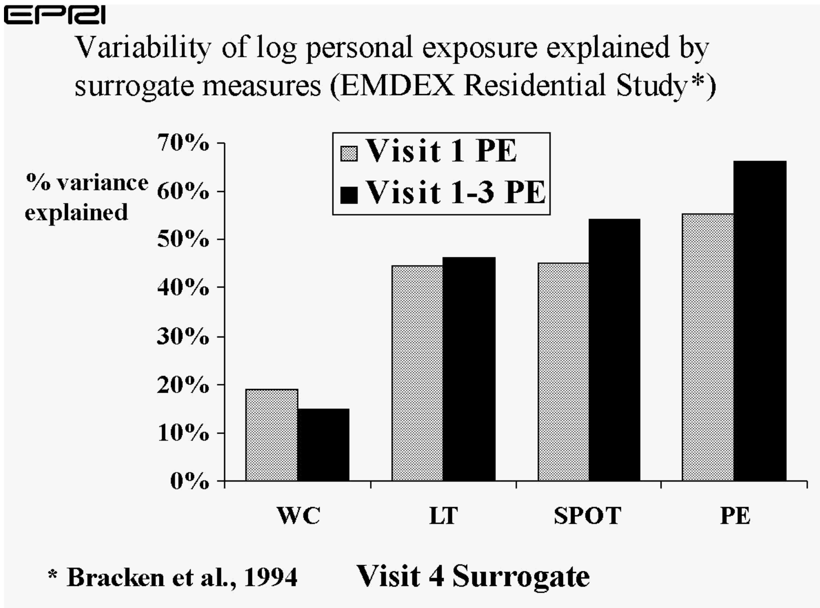

Figure 10-1. Variability of log personal exposure explained by surrogate measures.

Occupational Studies

Occupational studies have been of a retrospective nature, typically case-control; therefore, the goal of exposure assessment has been to recreate a history of an individual's exposure through job descriptions, which can be linked to estimates of magnetic fields. However, Kavet urged caution in adhering strictly to job titles as a surrogate for magnetic-field exposure. Even though certain electrical occupations in the utility industry have demonstrated elevated exposures compared to non-electrical workers, individual exposures within these groups can be very dependent on work environment and task.

As an example, Kavet cited distributions of PE measurements from general full-work-day measurement surveys of line workers at several utilities. These showed that magnetic-field exposures for line workers exceeded 0.1 mT (1 G) less than one percent of the time. On the other hand, if one looks at a particular line-worker task, a completely different picture of exposure may emerge. As shown in Figure 10-2, exposures of line workers connected to a 500-kV transmission line conductor and performing live-line maintenance tasks exceeded 1 mT (10 G) for 11 minutes (37% of the time) when replacing a conductor spacer. Thus, specific tasks that workers perform can dramatically affect individual exposures and can be an important factor in pinpointing highly exposed individuals.

Kavet noted that additional impetus for considering more than occupation in explaining magnetic-field exposure comes from work by Kelsh and colleagues, who analyzed exposure data from several studies of utility workers. They found that occupation explained only a small percentage of the variability, and that work environment was a more important factor than either occupation or utility. As an example of their findings, Kavet remarked that exposures for mechanics were highly variable, depending on the location of their work: mean exposures for this group were 1.1 mG in the shop environment, 1.3 mG in generation facilities, and 38 mG in substations. He suggested that the "mechanics" category might not best capture magnetic-field exposure in such situations, and that the work environment and even task should be considered as well.

RESULTS: Measurements While Bonded to 500-kV Conductor

500-kV Task	Field, mT	Time During Task	
		Percent	Minutes
Repair/replace spacer	> 0.05	69	21
	> 0.2	63	19
	> 1.0	37	11
Repair/replace deadened insulator	> 0.05	28	46
	> 0.2	15	25
	> 1.0	0.3	0.5

Source: Bracken et al., 1994

Figure 10-2. Results: Measurements while bonded to 500-kV conductor.

Summary

To summarize residential exposures, Kavet observed that, for TWA, a simple spot measurement leads to better classification than wire-code categories, at least for the previous year; and that surrogates for metrics other than TWA are not as well developed. He also noted that, for occupational exposures, there are significant sources of variance, but that job category is probably an important one, and emphasis should be on work environment and task. He closed by saying that surrogates are inevitable and indispensable and must be carefully evaluated because of their impacts on study design and efficiency.

SUMMARY OF DISCUSSION

Dr. Robert Kavet made the presentation on surrogates of EMF exposure. The discussion following the presentation and that during the general discussion period centered on several distinct but related issues. The summary below was prepared from the symposium transcript.

Surrogates

Cautionary points were raised about the use of surrogates. First, when considering a surrogate, it is important to distinguish between the relationship of surrogate to the exposure of interest and the relationship of the surrogate to disease (health outcome); then to evaluate the surrogate(s) depending on their purpose.

Kavet cited as an example of this distinction the job title “electrician,” which has shown a slight elevated risk for leukemia in several studies. This elevation might be due to magnetic-field exposure associated with being an electrician or with a number of factors combined that characterize electricians. If it is the latter, then the unit of exposure would be “electrician." If risk is associated with magnetic field, then it would be necessary to go back and examine environment and task to capture the identity of electricians with elevated exposures.

Second, a discussant noted that it is important to determine whether a given surrogate might be an "unintended" surrogate for another factor or factors: for instance, is wire-code category an unintended surrogate for air pollution associated with traffic in a transmission/distribution-line corridor, or is job title an unintended surrogate for life-style choices of, say, line workers. Thus it is possible that a surrogate might initially be selected as a surrogate for exposure, but then be shown to be a better surrogate for an unrelated factor more closely associated with risk. The following rhetorical question was asked in reference to surrogates, and to wire-code category in particular: how do you “un-enshrine” a surrogate?

Taking the issue of coincident exposures further, the discussant noted that it can be difficult to have an exposure assessment method that clearly identifies one factor over another. Higher wire-code categories in Denver were found in certain types of neighborhoods and tended to be coincident with high-traffic streets and presumably increased air pollution due to local traffic. The purported overlay of high magnetic fields with air pollution indicates that the use of a surrogate (such as wire-code category or even magnetic-field measurements to denote only magnetic-field exposure) may be naive. In other words, there are other exposures besides magnetic field associated with the infrastructure of the city.

With respect to confounders, it was noted that although investigators claim to address them, this is not always the case. Kavet noted that recent studies address and control for confounders and extraneous factors much more completely than earlier EMF studies did.

NCI Childhood Cancer Study

Following up on the discussion that wire-code category might be linked to some other causative agent, Kaune pointed out that if this is in fact true, then one must explain the negative results seen in the NCI childhood cancer study. The NCI study of childhood cancer did show an association between field measurements and wire codes, but did not show an association of disease with wire code category. The absence of an association with disease contradicted results seen in earlier studies. This seemed to him to be a significant result, because of the care that was taken in the NCI study. He suggested possible explanations: that the use of wire-code schemes could not be transferred to the geographical regions in the NCI study; and that either there was bias in the NCI study that removed the association or there was bias in the other studies that created it.

Kaune noted that a soon-to-be-published paper discusses how well wire-code category predicted fields in all nine states of the NCI study. The correlation of field with wire-code category was weaker in two of the states. Surprisingly, when these two states were eliminated from the case-control analysis, the association between wire-code category and leukemia weakened, rather than strengthened. Thus, Kaune sees the absence of an association with wire-code category in the NCI study as a key question to be explained.

In response to a question whether there seemed to be anything unusual about the population of houses in the NCI study, such as a predominance of rural houses, Kaune indicated that the houses were mainly, but not exclusively, from cities.

Case-specular Method

Several comments were made on the implications for wire-code schemes of the investigation of the case-specular method for selecting controls. Luciano Zaffanella developed and investigated the case-specular method; it has provided possible insight into the nature of wire codes and their transferability between geographic regions. The case-specular method selects a hypothetical control house, one that is the mirror image (across the street centerline) of the case house. This method is intended to eliminate confounding from socioeconomic and neighborhood factors

In revisiting the Denver area to apply the case-specular method to the residences of the original Savitz childhood cancer study homes, Zaffanella found that 90 to 95 percent of houses had the same wire code, indicating stability of the wire code over ten years. The case-specular analysis yielded higher risks of all cancers associated with wire codes than in the original Savitz study. In revisiting the houses of the Los Angeles childhood study, Zaffanella found that the results of the analyses were consistent with the original Los Angeles study.

In visiting the two sites, it was observed that in Los Angeles the location of distribution lines relative to houses was different than that in Denver. In Denver, about 95% of houses had a line in their backyard or back alley, while in Los Angeles the number of houses with backyard lines was about 50%.

When the Los Angeles houses were split into two groups, one with backyard lines and one without, the analysis with case-specular residences showed an elevated risk for the homes with backyard lines, just as in the Denver study. However, for the houses without backyard lines, there was absolutely no relation of risk with wire-code category. Zaffanella concluded from these observations that wirecodes are a good surrogate once you do a study in your own area and establish the relationship between wire code and the parameter of interest, but that the wire-code scheme developed in one area is not necessarily applicable in an another area.

In response to a question about whether the results with the case-specular method supported the interpretation of wire-code category as a surrogate for factors other than magnetic field, Kavet indicated that it was an innovative and interesting method that could help in determining whether a neighborhood factor or the location of three-phase lines were related to risk. However, its application was only beginning.

Wire-code Classification Schemes

One discussant emphasized the importance of four topics related to wire-code classification schemes: 1) the possibility of other correlates with wire-code category besides magnetic field; 2) the transportability of wire-code schemes between geographic regions; 3) the correlation of wire-code category with magnetic field; and 4) wire-code categories as an indicator of simply high and low exposure for epidemiology studies. The discussion of wire-code category as a surrogate for other factors was summarized above. In addition, it was noted that wire-code category offers an advantage: it focuses exclusively on external sources, compared with TWA PE and spot measurements, which do not distinguish between external and internal sources. Perhaps the positive associations of wire-codes with disease are indicating that it is *external* sources that should be examined. Kaune agreed with this observation and suggested that the association of disease with wire-code category indicates that external three-phase distribution lines and transmission lines—the lines that determine the high categories—are the important ones; this case would argue against the idea that some exotic characteristic of the magnetic field is associated with cancer.

The validity of transferring wire-code schemes from one geographic region to another was a major topic of discussion. It was explained in the light of both the NCI childhood leukemia study and applications of the case-specular method. (See summary of discussion for the NCI study and the case-specular method.)

In addition, Kavet pointed out that the infrastructure for electrical service was important and could change over time as well as be geographically diverse. For example, residential electrical service in the mid-Atlantic states might be different (for example, no distributions lines in back of house) than that in Denver where the original Wertheimer-Leeper wire-coding scheme was developed. (Wertheimer has said that their code was developed for Denver and caution is required in applying it elsewhere.) In addition to being different in different areas, the infrastructure of the electrical system might have changed over time. Kavet cited, as an example, the possibility that the principal source of field in a house might change from an external three-phase line to the ground currents in the house.

With regard to the ability of wire-code categories to indicate high and low exposure, Kavet remarked that they do perform reasonably, but still not as well as measured fields. Another commenter asked how could there be a good relationship between wire-code categories, when there is overlap of the fields from the lowest and highest categories. Kavet indicated that the relationship essentially arose from the number of VHCC houses with fields above 2 mG.

Kaune pointed out that if one were setting out to assess contemporary exposure, one would use measurements, not wire-code categories. Therefore the key question is: how well do wire-code categories predict historical exposures? He indicated that there was a relationship between wire-code category and measured fields in the NCI study, but that it was not as strong as in Denver or Los Angeles. In two of the states in the NCI study, the relationship between wire-code category and fields was weaker, indicating geographic diversity.

Kaune and others indicated the need to be aware of changes to the distribution system that might affect magnetic fields and/or wire-code category. He cited as an example a change in the primary distribution voltage from 4 kV to 26 kV in Seattle in about 1960: this might have changed the magnetic fields, but not necessarily the wire-code category.

Exposure Assessment Methodologies

Dr. Portier of NIEHS requested an evaluation by the presenters of exposure methodologies for both residential and occupational exposure: PE measurements versus job category for occupational exposures and 24-h TWA measurements versus wire-code category versus historical reconstruction of fields for residential exposures. In other words, if there were an association between, say, wire code and childhood cancer or between JEM and leukemia, how certain could we be that the relationship is actually between magnetic field and disease?

Kavet responded that, for exposures in the deep past, wire-code category may be the only indicator of exposure available. However, for more contemporary studies, the other measures—24-h TWA and reconstructed fields—become possible and will be emphasized. Wire-code categories will be left behind as a measure of residential exposure, even though they might have been markers for exposures associated with risk in previous data sets.

Bracken indicated that historical reconstruction of fields was possible only for transmission lines, and not for overhead distribution lines. Underground distribution can be classified as low field by wire-code category. However, the value of wire-code category for classifying the large number of houses near overhead distribution lines remains ambiguous. For these houses, the researcher is left with contemporaneous measurements as the preferred method.

Kaune indicated that his thinking on wire-code categories as a marker of exposure is very mixed at this point. In his view, the absence of a relationship between wire-code category and cancer in the NCI study greatly weakens the likelihood of there ever being such a relationship. The absence also weakens the argument that magnetic fields are the underlying cause for the previously observed relationship. However, Kaune noted that the relationship between historically reconstructed fields and childhood cancer in the Swedish study provides some evidence for a relationship between childhood leukemia and magnetic fields.

In response to the question about how strongly one can relate risk associated with a JEM to risk associated with magnetic field, Kavet expressed some reservation about whether that could be done routinely. He indicated that if such an association is present, then all resources—measurements, interviews and expert opinion—should be brought to bear on all environmental factors, including magnetic fields. He pointed out that the electric-utility workplace is not a simple environment, and requires careful analysis. Another commenter noted that considerably more is known about the electric-utility workplace with respect to facilities, tasks, and the resulting exposures than in other occupational settings. Therefore we can make stronger statements about relationships for occupations in the utility industry than for those in other industries.

With respect to questions regarding the reliability and validity of exposure-assessment methods, one discussant suggested that there are sufficient data available to answer many of the questions being raised about such methods, particularly if we are concerned with 60-Hz TWA exposures. For example, there would seem to be sufficient data available: to quantify and compare the uncertainties in the various methods for assigning residential exposures; to examine the consistency of exposures over time; and to determine the errors introduced by assuming that exposure is only from transmission lines in the Swedish study. The discussant suggested that quantitative analyses bringing all available data together could allow an objective evaluation of the various approaches. Such an analysis would examine the errors involved in each method and identify the main contributor to overall uncertainty; also, it could be done without additional exposure assessment projects.

Kavet cited an example of how uncertainty can be parsed out: the EPRI EMDEX Residential Study determined that between-visit variability to a house was not nearly as important as the variation between houses. This was reflected in the subsequent EPRI Long-term Wire Code study, where each house is treated as an entity that requires characterization.

Residential Predictive Model

Kavet described success with a predictive model for the log-transformed average spot-measured field levels in underground and VLCC homes in the 1000-home study, based on residential characteristics such as location (urban/suburban), net current, and the number of service drops from the pole. Discussants sought clarification on the degree to which the models were data-dependent and possibly not transferrable beyond the data-set in question, suggesting that a strong reliance on statistics alone might mislead the researcher as to how things work in the "real world." The model in question had been developed for the two lowest wire-code categories and then was applied to the next wire-code level up with success.

Exposure Parameters

One discussant identified two types of possible exposure parameters: continuous variables and yes/no indices. The latter refers to exposures where the researcher counts the number of times an exposure condition occurs, such as resonance conditions for calcium. The discussant asked what could be done in future studies to capture temporal information about these yes/no indices. Kavet responded that data are being analyzed from an EPRI study that visited 200 homes four times over two years, making PE, sophisticated wave capture measurements, and transients. These data should provide information on such indices over time.

Kavet further stated that statistical models are appropriate for extrapolating such data to many homes. Performing measurements becomes prohibitively expensive. He felt that the interest in these exotic parameters and indices was driven by the unexplained small increases in risk observed in epidemiology studies, whereas, when a laboratory scientist reports an effect from a clean 60-Hz field exposure, the need to invoke an exotic measure disappears.

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