



A Semiannual Report from EPRI's EMF and RF Health Assessment and Safety Program

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Dear Reader,

EMF Research News, published since 2006, covers prominent activities of EPRI's research concerning health and safety issues associated with power-frequency (50–60 hertz) electric and magnetic fields (EMF) and radio-frequency (RF) environments related to electric utility operations. We also summarize key EMF/RF developments external to EPRI, some of which—over time—have been influential in EPRI's formulation of its research priorities. The EPRI program, as always, remains committed to conducting relevant research and communicating the results in clear terms to all stakeholders. We hope you find items of interest to you in this issue, and we welcome your feedback and questions.

Thank you,

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The Basis for RF Contact Current Sensory Thresholds

A person touching an energized radio-frequency (RF) device, such as an antenna, experiences a continuous contact current that may cause tingling, warmth, pain, or other sensations. These sensations alert the person to break the contact before injury occurs. Unfortunately, there are few studies of human sensory thresholds relevant to continuous RF contact current exposure. Scientists need reliable dose-response information from such studies to set RF contact current exposure guidelines.

Rob Kavet of EPRI, Richard Tell, and Robert Olsen address this need in a [paper](#) published online December 8, 2013 in *Radiation Protection Dosimetry*. The paper reviews three laboratory studies previously used by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the Institute of Electrical and Electronics Engineers (IEEE) to set RF contact current exposure limits, and suggests a basis for the studies' inconsistent results.

As described in the paper's analysis, many factors may potentially influence sensory responses to RF contact currents. However, placement of the electrode delivering current to the skin and the skin's moisture content are suspected to have the greatest influence on sensory thresholds. Electrode placements distributing current density evenly across tissue resulted in higher sensory thresholds than placements distributing current density unevenly, due to so-called "edge effects."

The paper advises that, "Future well-designed and well-controlled studies with human subjects would contribute valuably to assuring that RF contact current exposure limits are specified at levels that provide for a safe environment." This is particularly true for studies of frequencies in the 20–110 megahertz range, where exposure limits exist, but experimental data are lacking.

New Software Calculates Magnetic Fields near Underground Cables

EPRI's recently released [software](#), the Magnetic Field Calculation Program, improves the design and assessment of underground cable installations. Based on UTWorkstation version 6.3M, the new software computes magnetic fields for pipe-type, extruded (XD), and self-contained fluid filled (SCFF) underground cables. Computations show magnetic field strength at various heights from the ground surface and distances from the center of the cable trench. Calculations for XD and SCFF cables draw on information from EPRI's 2008 [technical report](#), *EMF Management User's Guide for Underground Transmission Systems*.

Do DC Magnetic Fields from Marine Power Cables Influence Migratory Fish Behavior?

The Trans Bay Cable is an underwater direct current (DC) transmission line rated at ± 200 kilovolts and 400 megawatts connecting Pittsburg, CA to the Potrero substation in San Francisco, CA. With funding from the U.S. Department of Energy, EPRI and researchers from the University of California, Davis are investigating whether magnetic fields from the line will affect the migratory behavior of marine life. The high-voltage, DC Trans Bay Cable is a surrogate for cables that will serve future hydrokinetic installations, such as large offshore wind farms and generators powered by wave or tidal action.

The overall study plan is to measure and model magnetic fields in the San Francisco Bay estuary—along with environmental conditions that may influence fish behavior—at six locations where cross-bay arrays of acoustic detectors count fish tagged with ultrasonic transmitters. This plan will allow researchers to track tagged fish (steelhead, Chinook salmon, sturgeon, and cow sharks) as they migrate, and observe potential changes in their behavior that may be associated with the Trans Bay Cable. The study is scheduled for completion in 2015.

Electric Vehicle Charging—EMF Well Below Public Exposure Limits

Charging and operating electric vehicles generate electric and magnetic fields (EMF). As more people purchase electric vehicles, it is important to address public concerns by characterizing the EMF environment they create.

In a [paper](#) published online April 24, 2012 in *Bioelectromagnetics*, Richard Tell and colleagues reported that magnetic field levels measured in eight moving electric vehicles were "... much less than the exposure limits published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the Institute of Electrical and Electronics Engineers (IEEE)" for the general public. Now, EPRI has released additional results (November 2013 [final report](#)) describing electric and magnetic fields generated during stationary charging of electric vehicles.

At Southern California Edison's Electric Vehicle Test Center in Pomona, CA, researchers measured electric and magnetic fields up to 100 kilohertz associated with charging three different electric vehicles. The study included three conventional, alternating current chargers and two fast, direct current chargers. Measurements were made at fixed points inside and outside of each vehicle, along the surface of each charger, and without vehicles present (background). Of the 355 measurements recorded, "... measured fields were typically less than about 1% of exposure limits set by the IEEE for the general public." In fact, they were far lower in most cases.

EPRI Studies Cardiac Pacemaker and Defibrillator Performance in Electric Fields

As populations age, more people have cardiovascular active implantable medical devices (AIMDs) such as pacemakers and defibrillators. AIMD manufacturers are required to test their devices for potential malfunction or interference under a range of standardized conditions. The manufacturers generally indicate that their devices are immune to interference from power frequency electric fields up to between 4 and 6 kilovolts per meter (kV/m). But exposures at ground level under power lines operating at 735/765 kV can exceed these levels, approaching 10 kV/m. To fill the knowledge gap between 6 and 10 kV/m, EPRI has begun research to assess cardiovascular AIMD performance under high-voltage exposure conditions.

A 2011, *in vitro* study conducted at the high-voltage laboratory of the Institut de Recherche d'Hydro-Québec (IREQ) showed that AIMDs fabricated by a specific manufacturer, tested in normal programmed mode, were resistant to interference from 10 kV/m electric fields. These findings allowed the manufacturer to relax its cardiovascular AIMD electric field exposure limit from 6 to 10 kV/m and provide greater assurance to those with implants.

EPRI's new project—conducted at Hydro-Québec's IREQ Laboratory with the collaboration of the Montreal Heart Institute—will extend testing to AIMDs produced by four other major manufacturers. Study results characterizing interference thresholds for AIMDs from these manufacturers will provide better information to members of the general public and to electric utility workers with implanted devices for management of related safety issues.

First Study Published on ALS Mortality and Occupational Exposure to Electric Shocks and Magnetic Fields

In the first study of its kind, EPRI's Ximena Vergara and colleagues investigated the relationship between increased amyotrophic lateral sclerosis (ALS) mortality and occupational exposures to electric shocks (ES) and extremely low-frequency magnetic fields (MF). Amyotrophic lateral sclerosis, a fatal motor neuron disease that attacks the brain and spinal cord, has been linked to electrical occupations in the epidemiologic literature.

Using U.S. mortality data from 1991–1999, the authors identified 5886 workers whose deaths were attributable to ALS (cases), and 10 matched controls for each case. Workers were classified into low-, medium-, and high-exposure groups based on job-exposure matrices for magnetic fields and electric

shocks. The study found no significant association between increased likelihood of death from ALS and occupational exposure to electric shocks or magnetic fields. However, as previously reported by others, there was a moderate association between increased ALS mortality and employment in electric occupations—possibly due to “... some factor unrelated to ES and MF,” the authors suggest. Other risk factors may include exposure to metals, pesticides, or solvents, as well as strenuous physical activity and physical trauma.

The [study](#), published online June 11, 2014 in the *Journal of Exposure Science & Environmental Epidemiology*, was funded in part by the National Institute for Occupational Safety and Health.

Using Data from Personal Magnetic Field Monitors to Improve Exposure Classification in Miscarriage Studies

In 2002, two epidemiologic studies in which pregnant women wore personal exposure monitors suggested that maximum magnetic field exposures above 1.4–1.6 microtesla may increase the risk of miscarriage. But these studies relied on a single day of exposure monitoring. A more complete sample of magnetic field readings, together with detailed physical activity data, could reveal how much daily personal exposure measurements vary over time and correlate with activity. Researchers could use this information in future studies of reproductive health to reduce possible bias due to exposure misclassification.

In a [paper](#) published online April 2, 2014 in the *Journal of Exposure Science & Environmental Epidemiology*, Ryan Lewis and colleagues analyzed measures of magnetic field exposure among 100 pregnant women, recruited from North Carolina clinics in 2003–2004, who wore EMDEX II personal exposure monitors for 7 consecutive days. The investigators looked at variability over time for measures of both central tendency (for example, exposure averaged over time) and peak exposure. When these measures were modeled as continuous variables, single-day peak measures lead to substantial exposure misclassification compared with single-day central tendency measures. “If there is interest in peak personal magnetic field exposure metrics, more than 1 day of measurements is needed to minimize measurement error,” the authors conclude. The research was sponsored by EPRI and the National Institutes of Health.

Testing the Role of Selection Bias in Studies of Childhood Leukemia and Residential Magnetic Field Exposure

Selection bias can arise in epidemiology studies when investigators rely on voluntary participation by eligible subjects. It is possible that those who consent differ from those who do not in ways that influence the outcome of a study. Investigators have suggested that this bias may explain the observed association between exposure to magnetic fields greater than 0.3–0.4 microtesla and childhood leukemia.

A novel opportunity to test the role of selection bias arose in connection with the Northern California Childhood Leukemia Study (NCCLS). Recently, Danna Slusky and colleagues (including Gabor Mezei, who was with EPRI when the analyses were conducted) calculated residential wire codes for *all* eligible NCCLS case and control children—not just those whose families had agreed to participate in the study. (Wire codes, which are based on residential wiring configurations, serve as surrogates for actual magnetic field measurements taken by permission inside the home.)

Comparing various participating and nonparticipating case and control groups, researchers observed that “... the [statistically nonsignificant] association between childhood leukemia and wire codes is influenced by the characteristics of the control group and therefore [is] prone to selection bias.” Overall, “... no statistically significant association between wire codes and childhood leukemia is observed in the California population participating in the NCCLS.” The [study](#) was published online March 25, 2014 in *Cancer Epidemiology*.

TransExpo Study—Advances in Exposure Assessment, Design, and Data Collection

In epidemiologic studies addressing the association between residential magnetic field exposure and childhood leukemia, collection of residential magnetic field measurements requiring subject consent may introduce participation and selection bias. EPRI launched TransExpo, an international epidemiologic study designed to minimize this bias by using an innovative magnetic field exposure assessment method that requires no subject participation.

- **Overall Research Progress**

A December 2013 EPRI [technical update](#) describes TransExpo's methodology and ongoing feasibility and pilot studies, as well as the full-scale study involving several countries. Published results of exposure assessment pilot studies in six countries confirm—with remarkable specificity and sensitivity—that apartments directly above or adjacent to rooms with built-in transformers have higher magnetic fields than apartments located elsewhere in the same building. This finding allows researchers to classify children's magnetic field exposure based on apartment location, without family participation or apartment access. Feasibility and pilot studies are now under way in eight additional countries that meet study qualifications: transformers inside apartment buildings, as well as reliable cancer and population registries.

Ideally, full-scale, country-specific TransExpo studies would employ a cohort design, where the cohort includes "... all children who ever lived in a building with a built-in transformer during a specified study period." In its 2013 technical update, EPRI presents a cohort study protocol and alternate protocols that may be better suited to conditions in individual countries. Main data collection is under way in Finland, Israel, and Hungary. When data collection is complete in each country, the data will be pooled as part of the larger effort. Because childhood leukemia and high magnetic field exposure (above 0.3–0.4 microtesla) are rare, TransExpo requires collaboration among several countries to achieve a sample size large enough to support statistical findings with acceptable power and precision.

- **Exposure Assessment—Indoor Transformer Characteristics**

Magnetic fields measured in apartments directly above an indoor transformer room are significantly higher (typically at or above 0.4 microtesla) than fields measured in apartments further away in the same building. This method, demonstrated by researchers, will allow classification of children in TransExpo studies as exposed (living above the transformer room) or non-exposed (living elsewhere in the same building). Now, a [study](#) published online September 11, 2013 in the *Journal of Exposure Science & Environmental Epidemiology* by Enembe Okokon and colleagues asks whether exposure assessment can be improved by applying knowledge of indoor transformer structural characteristics.

In Finland, indoor transformers are described by type and location of secondary conductors. Using this information, EPRI researchers classified apartments in 30 Finnish buildings into one of three categories:

- high-exposure—apartments located directly above transformers with bus bars and cables near the ceiling,
- intermediate-exposure—apartments directly above all other transformer types, and
- background exposure—apartments on higher floors in the same building.

Analysis revealed an exposure gradient: "... both the time-averaged magnetic field and time above a threshold (0.4 microtesla) were highest in the high-exposure apartments and lowest in the reference apartments..." Although transformer characteristics can be used to predict magnetic field exposure due to indoor transformers, a simulation exercise showed that increasing the number of exposure categories from two to three did not noticeably improve discrimination between "low" and "high" exposures.

- **Exposure Assessment—Magnetic Fields near Stand-alone Transformer Stations**

EPRI researchers have measured magnetic fields near three stand-alone transformer stations similar to those installed in residential apartment buildings, as specified in the design for the TransExpo study of childhood leukemia and residences near electrical transformer rooms. The results, described in a [paper](#) published online July 7, 2013 in *Radiation Protection Dosimetry* by Shaiela Kandel and colleagues, support the TransExpo magnetic field exposure assessment method. That method assigns the “highly exposed” category only to apartments located directly above an indoor transformer station.

In their paper, the authors focus on stand-alone, outdoor distribution stations in Israel that are accessible from most directions and are useful for understanding indoor transformers. Measurements around and above the transformer stations indicated that low-voltage cables connecting each transformer to its switchgear were the main source of strong magnetic fields. Fields exceeding 0.4 microtesla were measured within 3 meters of the cables and within 2 meters of the transformer station ceiling, but rarely beyond.

Scientific Advisory Committee Reviews EMF and RF Health Assessment and Safety Program

On September 3–4, 2014 EPRI’s EMF and RF Health Assessment and Safety Program convened its Scientific Advisory Committee in Palo Alto, CA. The committee, composed of experts in epidemiology, exposure assessment, laboratory sciences, and engineering, has been meeting on an annual basis, with few exceptions, for the past 25+ years. The committee’s mission is to review the program’s scientific content, quality, and research directions, and to offer suggestions and course corrections, as needed.

Significant time was spent discussing the program’s research addressing the association of childhood leukemia with markers of magnetic field exposure (for example, residential proximity to power lines, calculated fields, and field measurements). The recent study in the United Kingdom (see sidebar) and the TransExpo study (see article in this issue) were the key focal points for this discussion.

The committee and guests also heard an update on an EPRI-sponsored study of pregnancy outcome in a cohort of women volunteers enrolled as patients in an assisted reproductive technology clinic in Boston, MA. EPRI-supported investigators covered other diverse topics, such as an exploration of magnetophosphenes (visual sensation of light flicker or flash) thresholds in human subjects exposed to magnetic fields under experimental conditions; a review of magnetoreception (detection of natural magnetic fields for biologically relevant purposes) across the animal kingdom; an update of the study of marine life migration in San Francisco Bay, sponsored by the U.S. Department of Energy (see article in this issue); and discussion of an EPRI-sponsored study in Australia of potential effects on electroencephalographic (EEG) patterns from radio-frequency exposure.

The program staff appreciates the care and attention provided by the committee as preparations for next year’s meeting get started.

Research Progress—Residential Distance to High-Voltage Power Lines and Childhood Leukemia

A large epidemiologic [study](#), conducted by Gerald Draper and colleagues in the United Kingdom (UK) and published June 2, 2005 in *The BMJ*, reported increased leukemia risk for children younger than 15 years of age living at birth in residences up to 600 meters from high-voltage (275–400 kilovolt) overhead power lines, compared with children living more than 600 meters away. Scientists found it difficult to attribute the increased risk at 200–600 meters to magnetic fields, since field strength is negligible beyond 200 meters from a source. To clarify the basis for the results, several research groups have replicated the main features of the UK Draper study.

France. In the [August 2013 issue](#) of *EMF Research News*, EPRI reviews work by French researchers who found that children living within 600 meters of high-voltage power lines had, overall, no more risk of developing leukemia than children who lived more than 600 meters away.

Denmark. In a [paper](#) published online November 7, 2013 in *Cancer Causes & Control*, Camilla Pedersen and colleagues in Denmark report that "... overall distance to nearest power line was not associated with higher risk of childhood leukemia." These investigators estimated magnetic field exposure for 1,577 cases and 3,191 controls based on the distance from birth residences to high-voltage (132–400 kilovolt) overhead power lines. Children living 0–199 or 200–599 meters from the lines had no elevated risk of leukemia, compared with children living 600 or more meters away.

United Kingdom. In the United Kingdom, Kathryn Bunch and colleagues expanded Draper's original work by adding cases (53,515 total) and matched controls for 13 additional years and estimating magnetic fields from high-voltage (132–400 kilovolt) overhead power lines up to 1000 meters away from birth residences. In their [article](#), published online March 4, 2014 in the *British Journal of Cancer*, the authors report, "... in aggregate ... there is no significant excess risk" over the 46-year study period. Relative risks were elevated in the 1960s and 1970s, but not in subsequent decades. Power line loads and associated magnetic fields increased from 1962 to 2008, but leukemia risk estimates appeared to decline. Thus, it is unlikely that exposure to magnetic fields could explain Draper's 2005 findings. "While a definitive conclusion cannot be reached, the results overall do not support an association between residential distance to power lines and leukemia in recent decades," EPRI reviewers conclude in published comments. However, the trend in results over time remains unexplained.

EPRI Comments. In comments published in [December 2013](#) and [March 2014](#), EPRI notes that a major strength of these large epidemiologic studies is the use of registries for case identification and control selection. Consulting national registries minimizes selection bias that arises when subjects must consent to participate in research.

However, these and other studies using residential-distance-to-power-line as a surrogate for magnetic field exposure may miss highly exposed subjects or fail to correctly identify unexposed subjects, thus biasing risk estimates. Finally, exposure assessment relying on a single address at birth may not capture exposures at separate addresses that could contribute to the development of childhood leukemia.

The California Power Line Study

This EPRI-sponsored replication of the Draper study, under way in California, uses improved methods to conduct a powerful test of the possible association between distance to power lines as a surrogate for magnetic field exposure and childhood leukemia. In a [paper](#) published online September 18, 2013 in the *Journal of Exposure Science & Environmental Epidemiology*, Leeka Kheifets and colleagues at the University of California, Los Angeles describe the study design and data analysis plan, as well as methods for case and control selection and exposure assessment. Strengths of this study include

- drawing cases and controls from state registries to minimize selection bias,
- paying careful attention to correct exposure classification to avoid biasing risk estimates,
- using residential-distance-to-power-line *and* calculated magnetic fields for those power lines to estimate risk, and
- developing a data analysis plan to answer questions about childhood leukemia before conducting statistical tests.

Upcoming Events

ICNIRP Joint Workshop on RF Field Health Effects & Standards

November 11, 2014, Wollongong, Australia. At this workshop, leading international experts will discuss the latest evidence for health consequences from exposure to radio-frequency (RF) fields and implications of that evidence for updating high-frequency RF exposure guidelines. The workshop is jointly sponsored by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and Australian research and safety agencies. More information is available at the [event website](#).

BioEM2015

June 14–19, 2015, Pacific Grove, California, USA. The invitation to participate reads: “With the increased presence of electromagnetic fields (EMF) in our everyday lives, the meeting aims at presenting and advancing high quality research in basic and applied aspects of bioelectromagnetics to address the medical applications, health concerns, and regulations associated with EMF.” BioEM2015 is jointly sponsored by The Bioelectromagnetics Society (BEMS) and the European Bioelectromagnetics Association (EBEA). More information is available at the [event website](#).

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