Electric and Magnetic Fields and Electric Transit Systems

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Over the past decade there has been increased public concern about possible health effects resulting from exposure to low-frequency electric and magnetic fields (EMF). Although the main attention has focused on utility companies' high-voltage transmission lines, this public concern over EMF is likely to have an adverse effect on the installation or expansion of electrified railroad, transit, or trolley bus systems. It is yet another reason for public opposition to new electric rail systems or system expansions. Concerns may come from a variety of areas, including people living or working adjacent to electrified transit routes, riders, operators, and maintenance personnel. In addition, railroad and transit systems frequently share rights-of-way (ROW) with public utility high-voltage transmission lines, often with the utility and transit company jointly occupying the same support structures. This greatly benefits both parties, especially in urban areas, where it is expensive and difficult to obtain the necessary ROW. However, this often results in transit passenger stations being located beneath or in relatively close proximity to the utility company's high-voltage transmission lines. Some of the more prominent developments in EMF research are reviewed and how the issues pertain to electric transit operations is discussed. It identifies the areas where long-term exposure to low-frequency EMF has been linked to health hazards, the reliability and controversy of these findings, and how these relate to AC and DC traction operations in terms of both real and perceived risks. Ways of reducing AC field strengths are reviewed, along with suggestions on how transit agencies can alleviate the concerns. Current research efforts, legislative efforts in the United States and worldwide, and state and federal standards are also discussed.

Any electrical conductor or apparatus is a source of electric and magnetic fields (EMF). Electric fields are a function of the electrical potential of the conductor and are expressed in terms of volts per meter (V/m).

The electric current flowing through the conductor creates a magnetic field. The strength of the magnetic field, also called the magnetic flux density, is measured in terms of lines of magnetic flux passing through an area at right angles to the flux. The unit of measurement of magnetic fields is gauss (G).

EMF can be either static (a result of DC voltage and current) or time-varying (a result of AC voltage and current). The earth's static magnetic field has a strength of about 1 G.

Concerns have been raised about the safety of long-term exposure to low-frequency EMF. Low frequency generally refers to the 3- to 3,000-Hz range. However, the most attention has focused on the commercial frequencies of 60 Hz (United States) and 50 Hz (Europe). In addition, certain industries (including electrified railroads) have traditionally used lower frequencies, i.e., 25 Hz (United States) and 16-2/3 Hz (Europe).

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Research indicates that if a health problem exists, it is a result of the magnetic fields rather than the electric fields. Therefore, this paper will focus primarily on the magnetic fields. Most of the research has pertained to the fields emitted by high-voltage transmission lines. A 1992 report issued by the Environmental Protection Agency (EPA) (*1*) provided typical field strengths emitted by various power lines in milligauss (mG) (see Table 1).

Because all electrical apparatus emits some level of EMF, a room is considered "clean" or free of low-frequency EMF if the level is less than 1 mG.

The issue of whether exposure to low-frequency EMF poses a health threat was first raised in 1979 when epidemiological studies by Wertheimer and Leeper (*2*) claimed there was a higher incidence of leukemia occurring in children living adjacent to overhead power lines. Since that time, a number of other epidemiological studies have also indicated that long-term exposure to low-frequency EMF (particularly in the 50- and 60-Hz range), both residential and occupational, increases the risks of certain cancers by as much as 2.5 to 3 times. These studies have been based on the configuration of overhead wires in the vicinity of residences, or on job descriptions, and have been based on calculated field strengths. However, these results have not been confirmed by studies that measure field strengths. In addition, biological studies have failed to provide any explanations to support this apparent effect, and other epidemiological studies have produced negative results.

Some experts contend that the low numbers of cases involved make the results questionable, implying that one or two cases would significantly alter the statistics. Also, it has been claimed that the studies may be influenced by confounding factors (herbicides or some other element associated with transmission lines rather than magnetic fields). Household appliances such as electric hairdryers, shavers, blankets, etc., and types of household wiring where the neutral wire is run separately from the line wire have also been cited as potential hazardous sources of magnetic fields. However, none of the studies to date have linked short-term exposure to magnetic fields with health hazards. Therefore, with the exception of appliances or wiring that would result in long-term exposure to magnetic fields, it is unlikely that these would pose a health threat.

The facts become very clouded by the emotional and legal issues surrounding the topic. Public attitude toward risk is greatly influenced by: (a) fear of the unknown and the unseen; (b) lack of control; (c) distrust of technology; and (d) potential harm to children.

All of these conditions apply to magnetic fields. In addition, high-voltage transmission lines and substation facilities are not welcome additions to residential communities and would almost certainly be strongly opposed regardless of the EMF issue, not to mention that this issue has already adversely affected property values, unquestionably the largest single investment that most people make in their lifetime.

TABLE 1 Transmission Line Typical Magnetic Field Strengths

		Magnetic Field (mG)				
		Distance From Line				
Voltage Level	Usage	Max. Row	15.25m (50 ft.)	30.5m (100 ft.)	61m (200 ft.)	91.5m (300 ft.)
115 kV	Average	30	7	2	0.4	0.2
	Peak	63	14	4	0.9	0.4
230 kV	Average	58	20	7	1.8	0.8
	Peak	118	40	15	3.6	1.6
500 kV	Average	87	29	13	3.2	1.4
	Peak	183	62	27	6.7	3.0

Information courtesy of Bonneville Power Administration

IMPACT ON UTILITY PROJECTS

Numerous cases have been cited in recent years in which public concerns over EMF have resulted in the delay or replanning of electric transmission lines and substations. Utility companies have considered and, in some instances implemented, various alternatives to reduce magnetic fields. These include: (a) wider ROW; (b) construction techniques, such as installation of additional static wires and split-phase construction (an example of how conductors can be rearranged to reduce field strengths on both single- and double-circuit lines is shown in Figure 1); and (c) replacing the transmission line with underground cables.

However, these techniques invariably result in significant increases in construction and maintenance costs, and in the case of split-phase construction, the potential for operational difficulties. One approach to this problem is to adopt what is known as the ALARA principle. This translates to reducing field levels "As Low as Reasonably Achievable." A guideline developed in Sweden is that field levels should not exceed 10 times normal if costs are not excessive. Some individuals have expressed concern with this approach because, to some extent, it reinforces concern by the public and workers that there must be some risk. However, in many instances it has been necessary to make some concessions just to keep vital transmission line, or substation projects on schedule. In addition, with the level of ongoing research, it would seem prudent to reduce fields if the costs are negligible. It also demonstrates that the industry is acting responsibly, thereby possibly increasing the "trust factor." In recent years, many projects have been delayed or even abandoned because of public opposition, with concerns over EMF health effects as the prime reason. In some instances, utility companies have changed routes and substation locations and even opted to install underground cables.

The following are some of the more recent incidents involving EMF. In November 1993, it was reported in the construction industry biweekly trade magazine *ENR* that a cogeneration project in Washington, D.C., had been put on hold until "more is known about the health effects of electrical and magnetic fields from reactivated power lines."

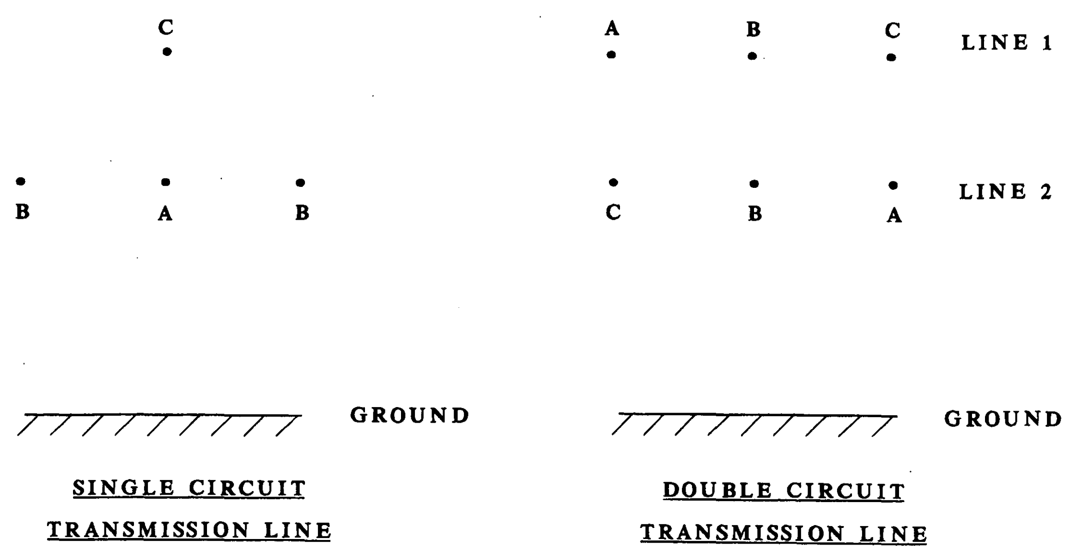

FIGURE 1 Examples of split-phase construction.

In another instance the energization of a 230-kV power line north of Philadelphia, Pa, was delayed 18 months because of protests about EMF issues. This was a former 132-kV, 25-Hz, single-phase line on Conrail's railroad ROW that had been reconductored and upgraded to a 230-kV, 60-Hz, three-phase line. Magnetic field strengths at the edge of the ROW were calculated not to exceed 26 mG under normal operating conditions (i.e., 90 percent of the time). In the final ruling on this case, the Administrative Law Judge concluded that there was no "conclusive causal connection between exposure to EMF and adverse human health effects because of the inconclusive nature of said research and studies." However, the ruling did require that should adverse health effects be scientifically established in the future, the utility company may be required to make changes to the line.

As recently as August 1994, the Clifton City Council and Education Board in New Jersey voted in favor of paying Public Service Electric and Gas Company (PSE&G) $35,000 to reconfigure a transmission line adjacent to one of the city schools. The State Regulatory Board had earlier required utility companies to measure magnetic field levels at all primary and secondary schools located near any transmission lines of 69 kV and above. Average readings between 14 and 22 mG had been recorded at the school in Clifton, which was the second highest reading in the state. In this case, PSE&G had refused to pay for the reversal of conductors, which it is calculated will reduce the EMF levels by 58 percent. The city will attempt to recover the money if it is later proven that these magnetic field levels pose health threats.

ELECTRIC TRANSIT SYSTEMS

Public concerns over EMF can affect electric transit systems in a variety of ways. First, utility companies and electric transit systems often share ROW, and passenger stations are located near the high-voltage transmission lines. Second, in the case of AC railroad electrification, the overhead catenary distribution system also is a source of low-frequency EMF. Also, AC electrification systems require high-voltage feeds from the utility companies, often at the 230-kV level to keep harmonic distortion and phase unbalance within utility-company limits. This may also require the construction of high-voltage transmission lines and obviously requires high-voltage substations.

DC systems also require power supply substations, although these are at a much lower voltage than the AC railroads. However, there is often no choice other than to locate these in residential areas. In the case of light rail and trolley bus systems, overhead power distribution systems are also required. However, these are low-voltage DC systems.

In addition, all electric transit vehicles contain electric traction motors that can generate relatively high magnetic fields.

It is clear then that all types of electric transit systems will result in some exposure to EMF for passengers, company employees, and people living adjacent to the transit lines.

AC ELECTRIFICATION

Problems with magnetic fields on AC-electrified railroads occurred long before the current EMF debate started. The high fields developed by the single-phase feed (the catenary) with rail and ground return result in high-induced voltage in any wayside conductors, or any other conducting material (*i.e.*, fences) that run parallel to and in close proximity to the track for any significant distance. This can result in interference in signal and communication circuits, and also results in unsafe induced voltages. Under normal conditions the induced voltage should be kept under 50 V, although higher voltages can be tolerated under fault conditions.

Descriptions of the two types of systems developed to mitigate interference and induced voltages follow

Booster Transformer System

With this system, a conventional center fed system has a return conductor with booster transformers added to its return circuit. The booster transformers are 1:1 current transformers with the primary windings connected in series to the catenary and the secondary windings in series with the return conductor (see Figure 2). The

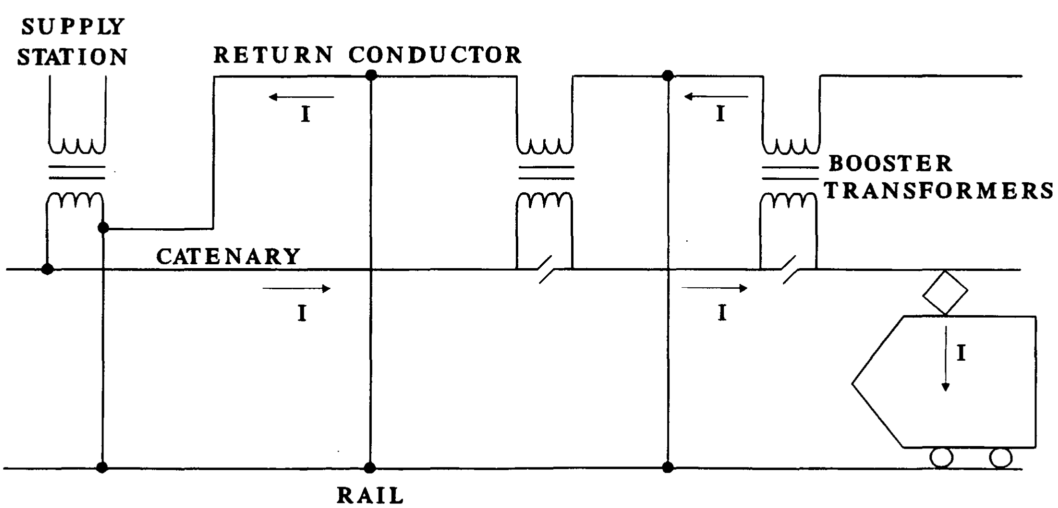

FIGURE 2 Booster transformer system.

return conductor is insulated from the catenary poles and is connected to the rails midpoint between booster transformers.

Because the booster transformers have opposing windings, the return current is forced into the return conductor. The return conductor is located between the catenary and the circuits to be protected, which effectively shields these circuits from interference. Booster transformers are placed approximately 1.6 km (1 mi.) apart for effective interference suppression. This coincides with the overlaps on auto tension catenary systems, which can be insulated to provide the section breaks for the booster transformer primary connections.

The disadvantages of the booster transformer system are (*a*) the capital cost, which includes the cost of the booster transformers; (*b*) the return conductor, which has to be sized to carry the same current as the entire catenary; and (*c*) possibly heavier poles and foundations to carry this heavy conductor. In addition, the impedance of the catenary and return circuit is increased by up to 30 percent, with a corresponding reduction in substation spacing by up to 30 percent.

The advantage is that booster transformers can be added only in sections where interference suppression is required. Although used extensively in Europe, the booster transformer system has not been used in the United States. Incidentally, a return conductor without the booster transformers can also be used to provide some shielding.

Autotransformer System

The configuration of the autotransformer system is shown in Figure 3. In this system, the power is supplied through the feeder and the catenary, and stepped down to the catenary to rail potential at the auto transformers. Once a train has passed an autotransformer location, the catenary current and feeder current are equal. As they are in opposite directions, the same mitigation is provided as with booster transformers.

The main advantage of the autotransformer system is that the bulk of the traction power is essentially transmitted at the catenary-to-feeder voltage. In modern systems, the feeder and catenary voltage are the same, *i.e.*, on Amtrak's New Haven-to-Boston line, both will be 25 kV. Earlier systems, such as SEPTA's former Reading Railroad, had a 22-kV feeder and an 11-kV catenary. This system was built in 1933 and is still in operation today.

The disadvantage of the auto transformer system is that the auto transformers are located further apart, usually about 8 km (5 mi). As the mitigation is not fully effective when trains are located between auto transformer stations (the same applies to booster transformer systems), there are longer periods when the interference mitigation is not fully effective.

The autotransformer system was originally developed to extend the railroad electrification systems into rural areas where power supply points were not available. This system is now attractive to minimize the number of supply substations because of the environmental problems encountered in building substations and high-voltage feeder lines.

DC TRANSIT SYSTEMS

Because the DC transit systems primarily generate static EMF, the same problems encountered with AC electrification systems do not exist. However, with the higher harmonic content of some of the

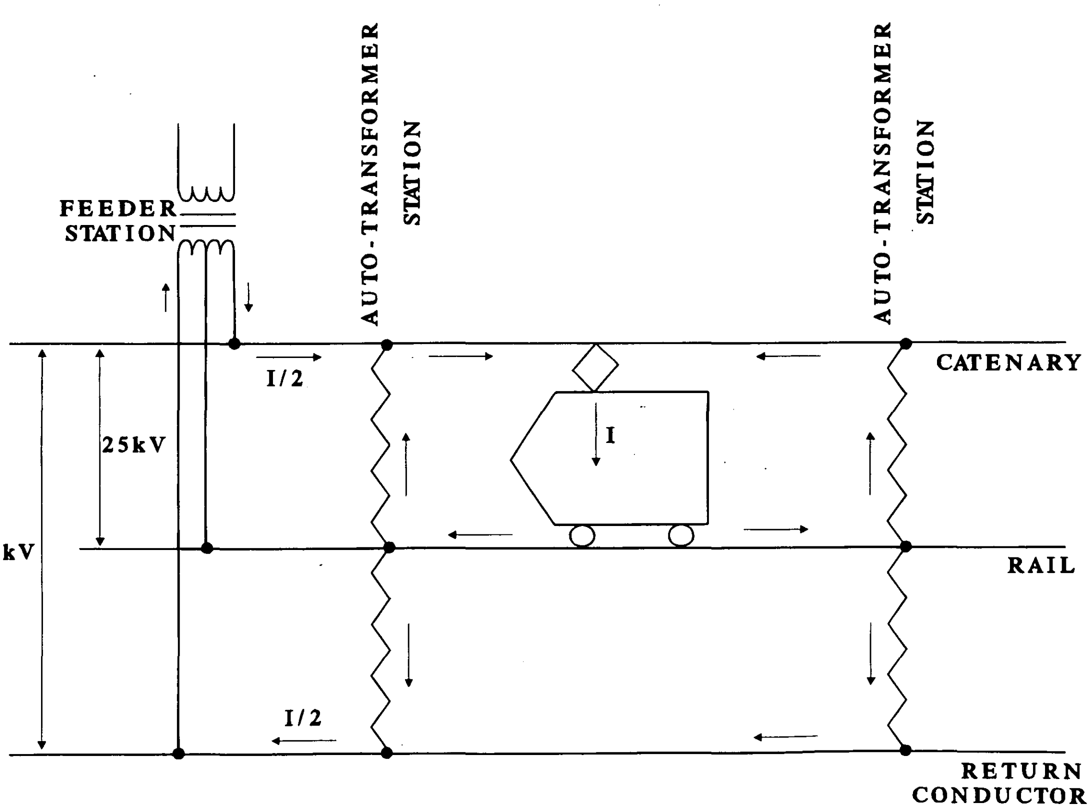

FIGURE 3 Autotransformer system.

newer traction motor systems, especially AC motors, some low-frequency magnetic fields are generated. However, it is extremely unlikely that these would result in any significant low-frequency fields being emitted from the traction distribution system. Nevertheless, these systems tend to be located closer to residences; therefore, EMF concerns raised by people living nearby should be expected.

Trolley coach systems have the added advantage that the positive and negative lines are located very close together, usually about 61 cm (24 in.) apart. This further eliminates the possibility of magnetic fields of any significance existing except very close to the overhead wires. In addition, the currents on these systems are generally far lower than other systems.

EMF RESEARCH EFFORTS

As stated previously, the concerns were raised in 1979 as a result of epidemiological studies conducted by Wertheimer and Leeper (*2*). A field study of homes in the greater Denver area was conducted in 1976–1977 that noted an excess of wiring configurations near homes where children had developed cancer. This study suggested that children in homes adjacent to overhead power lines had 2 to 3 times the risk of dying from certain types of cancer compared to other children. Although this study was heavily criticized, especially in terms of whether wire configuration could be accurately related to EMF, it did cause a lot of concern and spurred additional research.

In 1992 a report was issued by Feychting and Ahlbom (*3*) from the Karolinska Institute, Stockholm, Sweden, that again cited increased risk of childhood cancer in homes located near high-voltage transmission lines. This was considered a well-respected study. It not only analyzed wire configuration, but calculated field strengths based on utility company load records. Although this study again indicates an increased risk, the low number of cases involved may be insufficient to support this conclusion.

At the same time, various occupational studies (*4*) have been performed comparing job descriptions with incidents of cancer. Although the results of many of these studies indicate that individuals with electrical-type job descriptions have a higher incidence of certain cancers, it cannot be concluded that this is a result of EMF exposure or if it is the result of other hazards that electrical workers encounter in the workplace.

Laboratory studies have so far failed to provide any consistent findings to support concerns over EMF. It is generally agreed that if there is a link between EMF and cancer, it would be in terms of promoting rather than initiating the onset of the disease.

Although most of the research has focused on the utility industry, some research has been conducted in the transportation field. This has been mainly spurred by the increased interest in maglev and high-speed rail systems. Much work has been done as part of the Environmental Impact Statement for the New Haven-to-Boston Electrification Project, including measuring field levels on various railroad and transit operations.

TRANSIT EMF LEVELS

Prompted by the need to initiate high-speed electrification and maglev projects, the Federal Railroad Administration of USDOT sponsored research (*5*) into the EMF generated by various modes of electric transportation systems including maglev, 60-Hz and 25-Hz electric rail, 750-V DC (3rd rail) mass transit, and 600-V light rail transit (LRT) and trolley coach operations. This research has focused on measuring the EMF levels that passengers, transit workers, and people living adjacent to transit operations would be exposed to.

Not surprisingly, at most wayside locations the magnetic field levels were very intermittent, high when a train was in that feed section, and then rapidly falling off. Also, although the magnetic fields were sometimes relatively high adjacent to the tracks, these rapidly fell off as you moved away from the tracks. For example, a field strength of 100 mG, 9 m (30 ft) from the track fell to 10 mG, 30 m (100 ft) from the track, and at 92 m (300 ft) was less than 1 mG.

The magnetic field levels measured in the passenger compartments of various transit vehicles are given in Table 2, and on the platform area in Table 3, for a cross section of electric rail and transit systems. It should be noted however, that some of the higher fields, i.e., in the WMATA 3000 cars, occur close to the floor and fall off rapidly in the first 60 cm (2 ft).

TABLE 2 Magnetic Fields in Passenger Compartments on Trains

	Magnetic Field (mG)			
	Static		5-2560 Hz	
System	Maximum	Average	Maximum	Average
NEC(a) 11 kV, 25 Hz	1,763	606	782	133.8
NEC 11 kV, 60 H	1,039	630	408.4	52.5
NEC Non-electrified	1,033	569	26.5	5.2
WMATA(b) -Cam Cars (750 V dc)	4,714	1,103	64.8	9.4
WMATA-3000 Cars (750 V dc)	23,732	2,685	443.6	177.8
MBTA(c)-LRT (600 V dc)	1,981	534	68.4	5.7
MBTA-Trolley (600 V dc)	3,074	719	26.0	4.5
MBTA-Trolley Bus (600 V dc)	467	273	13.2	3.2

(a) Amtrak's Northeast Corridor
(b) Washington Metropolitan Area Transit Authority
(c) Massachusetts Bay Transportation Authority

TABLE 3 Magnetic Fields on Station Platforms

	Magnetic Field (mG)			
	Static		5-2560 Hz	
System	Maximum	Average	Maximum	Average
NEC(a)-11 kV, 25 Hz	970	422	550.8	39.6
NEC(a)-11 kV, 60 Hz	1629	650	417.6	62.2
NJT(b)-11 kV, 60 Hz	615	525	213.2	28.8
WMATA(c)-750 V dc	2065	455	66.6	3.1
MBTA(d)-600 V dc catenary	1718	612	82.0	8.6

(a) Amtrak's Northeast Corridor
(b) New Jersey Transit
(c) Washington Metropolitan Area Transit Authority
(d) Massachusetts Bay Transportation Authority

REGULATIONS AND STANDARDS

Currently no regulations exist in the United States governing the allowable levels of EMF. Both Florida and New York have established standards for the maximum EMF levels for transmission lines. However, it is interesting that neither of these standards is health related.

Florida's standards for 230-kV or smaller lines are:

1. Electric field	8 kV/m	maximum
	2 kV/m	edge of ROW
2. Magnetic field	150 mG	(max load) edge of ROW

New York's standards are:

1. Electric field	11.8 kV/m	maximum
	1.6 kV/m	edge of ROW
2. Magnetic field	200 mG	(max load) edge of ROW

The World Health Organization recommends limiting long-term exposure to electric fields between 1 and 10 kV/m. Its recommendations for magnetic fields are 20,000 G for static (DC) fields and (by proportion) 10 G at power frequency levels.

The International Radiation and Protection Association (IRPA) established maximum limits of 1 G (24-hour exposure) to 10 G for a few hours per day.

The National Radiological Protection Board NRPB (UK) (*6*) has established similar standards. However, this document also references the Swedish and Danish (*7*) epidemiological studies and concludes that these were "well controlled and substantially better than those that previously reported association with childhood cancer." However, the document goes on to state that the studies report few cases, and do not establish that exposure to EMF is a cause of cancer. It does acknowledge that the studies provide "weak" evidence that the possibility exists, but contends the risk, if any, would be very small.

The EMF issue has also been of concern to the electrical engineering professional societies. The Institution of Electrical Engineers in the United Kingdom (IEE) established a Health and Safety Committee in 1992. In May 1994 the IEE issued a preliminary view "that there is nothing in the currently available evidence to prove the existence of the effects claimed. If any such effects do exist, then their incidence within the population, taken as a whole, must be very small." The IEEE in the United States has issued similar position statements.

As stated, no federal regulations have been established. However, government involvement has recently increased. H.R. 1665: The Electromagnetic Labeling Act of 1993 was recently introduced in Congress. This bill would have required products with field strengths greater than 100 mV/m and 1 G when measured 2.5 cm (1 in.) from the product to be labeled with simple information on the EMF emitted from that product. So far this bill hasn't made much headway because current research has not established a clear link between EMF and health effects.

However, Section 2118, Electric and Magnetic Fields Research and Information Dissemination Program of the U.S. Energy Policy Act of 1992, authorized the appropriation of $65 million for research efforts from Fiscal Years 1993 through 1997. The purpose of this program is to:

1. Determine whether exposure to electric and magnetic fields produced by the generation, transmission, and use of electric energy affects human health;
2. Conduct research, development, and demonstrations with respect to technologies to mitigate any adverse human health effects; and
3. Disseminate information to the public.

OTHER SOURCES OF EMF

Of course there are many other sources of magnetic fields both in the house and in the work place. The EPA document issued in 1992 lists various appliances with the lowest, medium, and highest levels of magnetic fields measured at various distances from the item. A few of the higher ranked household appliances are listed in Table 4 (higher values only).

Conventional electric blankets have peak values of nearly 40 mG, 5 cm (2 in.) from the surface, although newer-model positive temperature coefficient (PTC) low-magnetic-field blankets have fields less than 3 mG, 5 cm from the surface.

Therefore, while many appliances can generate high fields close by, they generally fall off rapidly.

TABLE 4 Household Appliances

	Magnetic Field (mG)			
	Distance			
Appliance	15 cm (6 in.)	30 cm (12 in.)	61 cm (24 in.)	122 cm (48 in.)
Hairdryer	700	70	10	1
Electric Shaver	600	100	10	1
Can Openers	1500	300	30	4
Microwave Oven	300	200	30	20
Mixers	600	100	10	-
Vacuum Cleaners	700	200	50	10
Color TV	-	20	8	4

\- Data not available

OTHER FACTORS

Aside from the inconclusive results of the scientific research to date, many other issues cloud the debate on the seriousness of the EMF health issue.

Various media articles have sensationalized the topic, sometimes making it difficult to separate fact from fiction. Probably the most famous are the articles in the *New Yorker* by Paul Brodeur, followed by his books, *The Currents of Death* and *The Great Power Line Cover-up*. In addition, the issue has been covered in movies, a variety of news magazines, and numerous newspaper articles.

A variety of legal actions have stemmed from the EMF issue, many settled out of court. As a result of the potential for litigation, many utility companies have been reluctant to openly discuss the issue.

In addition, the general distrust of the public toward industry is a major factor. Chernobyl and Three Mile Island in the nuclear industry, and Love Canal and numerous other incidents regarding hazardous materials tend to make people fear the worst, even when the scientific evidence regarding EMF is relatively weak.

Of course another major problem is the "Not In My Back Yard" (NIMBY) syndrome. High-tension power line projects were being strongly opposed for aesthetic reasons long before the EMF debate. Similarly, high-speed rail, especially electrified, and most electric transit projects usually face strong opposition from adjacent property owners.

As a result of the EMF concerns, property values have generally declined in residential areas adjacent to high-voltage transmission lines and substations.

Finally, because of the uncertainty on how, if at all, EMF is a health hazard, it's difficult to equate the risk associated with EMF with other risks encountered in everyday life. It's interesting that many people voluntarily expose themselves to risks much greater than EMF, such as smoking. Even the concerns over radon gas seem to have declined in recent years.

CONCLUSION

It is unlikely the question concerning exposure to relatively low levels of low-frequency EMF as a health threat will be conclusively answered in the near future, if ever. Therefore, the railroad and transit industry must be prepared to address the concerns of riders, workers, and people living adjacent to electrified transit operations.

From the research and measurements taken to date, it can be concluded that although maximum wayside values of magnetic fields are relatively high on AC railroads compared to utility lines, these are of short duration. In addition, riders would only be exposed to these fields for a relatively short period of time. Not surprisingly, DC systems exhibit much lower magnetic field values.

Similarly, low-frequency magnetic fields on board the vehicles are much higher for AC electric railroads than for DC systems, with the fields on the electric trolley bus being the lowest. However, it is noted that a relatively high AC field was recorded on the WMATA 3000 cars. Therefore, even DC traction systems must be considered a potential source of low-frequency EMF, especially those with modern traction drive systems.

Public concern over the safety of EMF continues to plague the utility industry, attracting a lot of media attention. Early in 1994, an EMF-monitoring device was advertised in a mail order brochure of "home safety gadgets." This monitor was calibrated from 1 to 24 mG, with three zones, from green (safe) to red (potentially unsafe), and sold for $99.95. With this in mind, it could be hard to convince the public that fields of 1,000 mG are safe. Therefore, to avoid enabling the EMF issue to become a deterrent to new transit system starts, it is important that research continue in this area and that the results are disseminated throughout the industry.

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