The subjects for the second pilot study were two groups of employees at an electronics manufacturing plant. Either they kept a time-activity diary or their activities were recorded by an observer during work hours. Several steps were taken during the pilot study to ensure reliability of the data: calibration of instruments was verified before and after the project; functionality of each axis of the meter was verified before measurements were taken; forms were designed to be clear, succinct, and straightforward; the investigator emphasized the importance of data accuracy to participants; the data were reviewed immediately following collection; each participant was assigned a unique six-digit code that was recorded on all forms and data files; and PE measurement EMDEX files were reviewed for quality and backed up on floppy disks before being sent for production of summary data. Average exposure for all professional employees during the study was 0.9 mG. Two employees had substantially higher mean exposures than the other five employees: 1.26 mG and 2.06 mG vs. 0.49 - 0.74 mG. These two employees worked in the same general area and were exposed to the fields from the same printer.

Background Materials

The document contains a literature review of PE measurement studies that provides background information and reference to works presenting PE measurement protocols and related issues. Selected references have been summarized in a standard format and included as an appendix.

To illustrate the effects of subject characteristics on activities possibly related to EMF exposure, existing time-activity survey data for children and adults in California were examined. The largest and most consistent differences in locations and activities observed in these data were related to age and gender. The differences suggest that these should be important subject attributes in an EMF PE measurement study.

Study Limitations

The guidelines reflect the technology that was available at the time of writing.

The guidelines represent judgements regarding study design. They cannot provide a definitive approach to personal exposure monitoring for EMF. Approach will depend on the purpose of the study and resources available.

Areas for Future Research

Improvements in instrumentation: reduction in size, ability to capture spectral information.

Better information or approach to time/activity recordkeeping as it relates to EMF.

Summary

The combination of the general guidelines, specific guidelines, and background materials provides a prospective investigator of EMF PE with a foundation for developing, implementing and reporting a scientifically sound, valid PE measurement study.

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EMF RAPID Engineering Project #5
Development of an EMF Measurement Database

Purpose and Focus

The primary goals for this project were as follows:

1. to develop a database structure that could accommodate the diversity of EMF data sets,
2. to provide guidance for production of future EMF data sets, and
3. to serve as an accessible repository of EMF measurement data.

The EMF measurement data sets currently in existence were compiled with varying goals and techniques. Consequently, they have different information content as well as varying logical and physical structure. Future studies will continue to pursue varying goals and to use techniques that cannot be known in advance.

Specific objectives of the EMF Measurement Database were as follows:

- to preserve study descriptions, results and data;
- to provide readily accessible, well-documented data; and
- to facilitate communication among researchers.

In addition, the EMF Measurement Database was to encourage additional analysis of existing data sets, facilitate analysis of data from multiple projects, support design of new studies, and permit future issues in EMF exposure assessment to be addressed with existing data.

Tasks: Goals and Methods

The investigators used a formal, but open, structure to preserve study descriptions and data. Specifications were developed for the various elements of the database. Each data set in the database was formally described by a metadata file. For each data set, the structured metadata file described the following:

- origin,
- development,
- logical and physical structure, and
- distribution mechanism.

The metadata for each data set was generated according to a specification developed for the EMF Measurement Database.

The actual measurement data were contained in data products for each data set. The number and type of data product vary by data set. Most of the data products in the possession of the EMF Measurement Database are available for download from an Internet site (http://www.emf-data.org). The site consists of numerous HTML documents describing the various features of the database, as well as providing the metadata for available data sets. It provides descriptive information in a home page, access to data products with a file transfer protocol (ftp) address (ftp://www.emf-data.org), and links to other EMF-related sites. Electronic mail can be sent to the Database at info@emf-data.org. (For some data sets, the data products will be maintained by other parties who may have their own access procedures.) By providing a Web site, the project will achieve a third objective: fostering communication among researchers by providing ready access to data and information about EMF studies.

Researchers contributing data sets are encouraged to submit reports consisting of text, tabular, and graphic information describing their study and analysis of facts. In addition, data-set contributors or users can provide reports that describe results of the study and analysis of the data with text and figures. Guidelines have been developed for preparation of reports. A Data Set Submission Kit includes specifications, the form, and an optional software package to prepare the metadata in the specified Standard General Markup Language (SGML) format. Alternatively, the researcher may submit the existing data and the database maintainers will organize the metadata.

It is important to note that the Web site exists as a clearinghouse only. Reports are not validated by the service. The project report covers issues of Intellectual Property. Data products and related materials are available for use under a liberal user license that allows modification and redistribution.

Current data sets available at the Web site include the following:

001 Personal 24 Hour Emdex Pilot Project: Lynne Gillette and Doreen Hill, EPA, 1992.

This project involved twenty volunteers who wore EMDEX C meters for 24 hours (including a typical work/school day) and logged information about their activities and possible sources of magnetic fields they encountered. Most of the subjects (18) were federal office workers, one was a middle school student, another was a horse stable operator. Magnetic fields in the ELF range were collected at 10 second intervals. Six data products are available for this data set.

002 Household Appliance Magnetic Field Data: James R. Gauger, IIRTI, 1983.

The results of a non-comprehensive survey of the 60-Hz magnetic fields produced by common household appliances and tools are reported. Maximum magnetic-field levels as a function of distance for 95 appliances of 27 basic types are characterized. The measurements represent the highest magnetic fields generated by the appliances in any normally accessible direction from them. All sets of measurements but two were made at the fundamental powerline frequency of 60 Hz and all represent narrowband rms levels of magnetic flux density. Measurements at powerline harmonics and other frequencies were not made. The data presented should be useful in understanding the levels of magnetic field produced by household appliances and also in estimating magnetic-field exposures in homes and workplaces. One data product is available for this data set.

003 DOT Conventional Vehicle Study: Electric Research and Management, Inc., 1997.

Magnetic fields in and around five vehicles were measured using the MultiWave wave-capture device. Measurements were made over 9 road types during 57 sessions. Up to 12 3-axis magnetic-field probes were deployed simultaneously at multiple positions within each vehicle. Additionally, external measurements were performed around the perimeter of each vehicle. The purpose of the study was to help characterize the magnetic-field environment in conventional transportation environments. The data collected are intended to serve as a baseline against which other existing and emerging transportation technologies, such as electric vehicles, can be compared. Three data products are available for this data set.

Study Limitations

- The inventory of data sets available through the Database is still quite small. Addition of new data sets can be time-consuming.
- No reports have yet been submitted by contributors.
- The problem of presenting inherently complex information in a simple way has not been solved.

Areas for Future Research

Additional data sets will be integrated into the Database. Improvements to the presentation of metadata will continue.

Summary

The EMF Measurement Database established by this project provides a readily accessible (via Web site) source for researchers to obtain current information on related research. Researchers may also submit their own work in the form of text, tables, and graphics, for inclusion in the database. Each data set is accompanied by a metadata set that describes the nature of the data available. The metadata may be organized either by the submitter using a software package supplied by the Database maintainers or by the maintainers themselves. The research results submitted by contributors are not validated by the service.

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EMF RAPID Engineering Project #6:
Survey of Personal Magnetic-field Exposure
Phase I: Pilot Study and Design of Phase II
Phase II: 1000-Person Survey

Purpose and Focus

The objective of this project is to characterize personal magnetic-field exposure of the general population, by performing personal exposure (PE) measurements for a sample of the population. The project is in two phases:

- Phase I was designed to develop survey methodologies and to conduct a small-scale survey.
- Phase II includes a large-scale survey using the methodology developed in Phase I.

To achieve its goal, Phase I included two separate tasks:

(1) a survey of personal magnetic-field exposure on a sample of 200 randomly chosen adult individuals in the United States (“200-person statistical sample”), and
(2) the development and testing of the protocol for Phase II. As a part of this task, PE measurements were made on a sample of conveniently chosen individuals, including infants, toddlers, school age children, and adults (“convenience sample”).

Recommendations for Phase II are derived from the analysis of the 200-person statistical sample survey, from the experience in conducting the survey, from the work performed to develop the protocol, and from the feedback received from participants in the convenience sample.

Tasks: Phase I

Two-hundred-person Statistical Survey

The protocol for the 200-person statistical sample consisted of the following steps:

(1) Households were randomly selected from listed telephone numbers.
(2) An introductory letter was sent, followed by phone calls until a contact was made. The respondent was interviewed in order to select a household member.
(3) The persons who agreed to participate were sent a Consent Form to be signed and detailed explanations about the purpose and the nature of the measurement survey.
(4) Upon return of the signed Consent Form, participants were sent a package containing a personal exposure meter, a diary, a questionnaire, a $50 check as

compensation for their participation, and detailed instructions on how to use, wear, and mail back the meter.

(5) Participants wore or kept the meter with them for 24 hours from the moment when they first turned the meter on. Magnetic-field values were recorded and stored in the meter's memory every four seconds. The participants used a diary to record the time when certain activities started or ended. After 24 hours of measurements, they mailed the meter back.

(6) The meter's data were transferred to a computer file, merging information from the diary with the magnetic-field data. The magnetic-field exposure for the entire 24 hours and, separately, for different activities were calculated.

(7) Participants received a letter with the results of their individual measurements.

(8) The data were placed in a database and subsequently analyzed.

Based on the time- and event-data in the activity diary, the measurements in each data file were partitioned into the following categories: at home not in bed, at home in bed, at work, at school, during travel, and other. A variety of measures of the magnetic field were extracted for each subject and for each type of activity, including time spent for the activity, mean, mean, standard deviation, geometric mean, and maximum. The 24-hour time-weighted-average (TWA) results are shown in Tables 1 and 2.

Table 1: Number of Survey Participants with TWA Exceeding Given Values

24-Hour TWA (mG)	Exposures Exceeding Given Value (Number)	Exposures Exceeding Given Value (%)
0.0	201	100.0
0.5	162	80.6
1.0	105	52.2
2.0	37	18.4
5.0	5	2.5
10.0	1	0.5

Table 2: Descriptive Statistics of 24-Hour TWAs

Parameter	Result
Minimum	0.17 mG
Median	1.05 mG
Maximum	19.60 mG
Mean	1.41 mG
Standard Deviation	1.70 mG
Geometric Mean	1.02 mG
Geometric Standard Deviation	2.17

Participants were asked to keep a diary of their activities so that magnetic-field exposure could be evaluated not only for the total 24-hour period but also for different types of activities. The results for different activities are shown in Table 3.

Table 3: Descriptive Statistics for Different Activity Periods

Parameter	At home not in bed	At home in bed	At work	During Travel	Other	All activities
Number of Valid Data Sets	**181**	**182**	**128**	**158**	**162**	**201**
Average activity time of the people with valid data for each activity (% of 24 hr)	33.50	33.20	31.50	9.30	13.00	100.00
Minimum	0.08	0.00	0.08	0.23	0.07	0.17 mG
50th Percentile (**Median**)	0.85	0.61	0.97	1.14	0.90	1.05 mG
99th Percentile	5.94	12.10	7.23	5.03	7.99	7.05 mG
Maximum	14.20	62.00	8.49	6.65	11.80	19.60 mG
Mean	1.22	1.61	1.47	1.36	1.27	1.41 mG
Standard Deviation	1.46	4.88	1.56	0.92	1.39	1.70 mG
Geometric Mean	0.80	0.61	0.94	1.15	0.91	1.02 mG
Geom. Standard Deviation	2.47	3.83	2.63	1.74	2.20	2.17

The exposure distributions were affected by a number of parameters. The greatest effect occurred for the following parameters:

- variations of residence type (duplex residences corresponded to the highest exposures during the “at home” time, followed by apartments and single-family homes),
- proximity to overhead power lines (the largest exposures at home occurred for power lines closer than 25 feet to the residence and the lowest for residences with no overhead lines nearby),

- the residence size (the largest exposures at home occurred for residences with a floor area less than 1000 square feet, while residences with floor area greater than 2000 square feet corresponded to the lowest average exposure, which never exceeded 2.5 mG),
- the floor location of the bedroom (the lowest exposures at home in single-family residences occurred when the person's bedroom was on the second floor), and
- the type of water line (the largest exposures at home occurred when the water line was metallic).

The following conclusions could be drawn from the 200-person sample.

(1) The distribution of the fields during a 24-hour period is estimated to be log-normal, with a geometric mean of 1.02 mG (95% CI from 0.88 to 1.16 mG) and a geometric standard deviation of 2.17 (95% CI from 2.09 to 2.26).

(2) The distribution of the time during a 24-hour period during which the field exceeded 10 mG has a geometric mean of 1.84 minutes and a geometric standard deviation equal to 7.8. The time above 10 mG exceeded 1 hour for 10% of the people.

(3) The distribution of the time during a 24-hour period during which the field exceeded 50 mG has a geometric mean of 0.12 minutes and a geometric standard deviation equal to 4.0. The time above 50 mG exceeded 10 minutes for 2.5% of the people.

(4) The largest TWAs were recorded "at home, in bed"; followed by "at work"; "at home, not in bed"; and "during travel." The lowest TWA were recorded "at home, in bed." The category of "at home, in bed" has both the lowest and the highest exposures. The distribution of the average field "at home, in bed," has the largest variance.

(5) In general, larger TWAs were recorded for men than for women. The period "at work" appears responsible for the difference.

(6) The following parameters appear to affect the distribution of exposures at home: residence type, proximity to an overhead power line, residence size, location of the floor of the bedroom, and the type of water line. The data were too few to investigate the effect of other parameters, such as occupation and type of overhead power line.

Development of the Survey Method for Phase II

A cost-effectiveness analysis of several different survey methods differing for meter selection, sample designs, and survey protocols was performed, considering (1) the cost of the survey, (2) the expected variance in the results, and (3) the quality of the information obtained.

The analysis revealed that area probability sample design overall has better properties if cost is not a serious consideration. A random digit dialing (RDD) sample design, on the other hand, is recommended if the survey cost has to be constrained. In this case, the most cost-effective method is achieved using a RDD sample design (including telephone recruitment), a mailing out of the instruments to the sampled persons, and instruments that can be easily worn and do not require much input from the user. This overall design avoids the cost of a visit to the user's residence. It requires, however, recruitment of the participants by telephone, which results in a refusal rate significantly greater than that which could be achieved by visiting the user's residence. In addition, mailing the instruments out (rather than personally delivering of them to the household) will also involve the extra loss of participation by persons who agreed to cooperate at the recruitment stage, but who fail to follow through in agreeing to use the meter.

The PE measurements on a 200-person sample constituted a pilot program for a much larger sample to be measured during Phase II of the study. However, several aspects of the protocol were not tested, and several others needed further testing. For example, the 200-person sample consisted only of adults, and a detailed debriefing of the participants was not possible. In order to formulate recommendations for the protocol to be used in Phase II, additional PE measurements were made on several infants, toddlers, school age children, and adults chosen among a "convenience sample" consisting of 53 people: 12 infants, 13 toddlers, 16 school age children, 6 adult males, and 6 adult females. When PE measurements were made of toddlers, PE measurements were simultaneously made of their mothers as well. For each school-age child, three different protocols were tested on three different days. The results have little statistical significance because the sample was small. It appears that the adults in the tested sample had considerably greater exposure than children, toddlers, and infants. The toddlers in the tested sample had considerably less exposure than their mothers, whose exposure data could not be used as proxy for the toddlers' data.

The results obtained during the 200-person exposure survey, the experience gathered during the tests performed with the convenience sample, and the results of the cost-effectiveness analysis of different survey methods were used to make the following recommendations for Phase II:

- The option of performing special measurements (DC, waveform capture, wire code) should be abandoned because it is too expensive, since it requires visiting the residences of the participants.
- No special stratification is justified.
- The cost of including institutionalized people (hospitalized, nursing homes, military, prison population) is not justified.
- The optimum instrument recommended for Phase II is one with a fast sampling rate (every 0.5 seconds), permanent memory, small size, and capability of storing in memory frequent (e.g., once every 10 minutes) detailed summaries of the exposure quantities.
- Survey participants should be recruited by telephone. The sample design should incorporate a list-assisted RDD method. The phone interviewer should use the same techniques used during Phase I to administer a questionnaire, make the selection, and solicit the participation of a member of the household.

- A consent form and a letter that illustrates the reasons and modality of the survey should be sent to all those who have agreed to participate.
- Upon return of the signed Consent Form, the participants should be sent a package containing a personal meter, the instructions for the its use, a small diary in which to record the type of activities performed, a questionnaire, a UPS envelope with prepaid label for returning the meter, and a $50 check for compensation for participation in the study.
- The PE meter should be the size of a pager, and it should be possible to clip the meter to a belt or place it in a pocket. For infants and toddlers, the meter should be placed inside a teddy bear kept near them for the day of the measurements.
- The only action required from the participants should be to turn the meter on at the start of the 24 hours of recording. Participants should be asked to note in the diary the time of day when the meter is first turned on, and then the time at every change of the following types of activity: at home, in bed, traveling, at work, at school, and other activities.
- The participants should be asked to ship the meter, diary, and completed questionnaire as soon as possible after the 24 hours of exposure measurements.

Study Limitations

Several factors limit one ability of the small-scale survey to support statistical inferences for the general population. The survey did not cover non-telephone households (about 5% in the U.S.) or households with unlisted telephone numbers (about 30% in the U.S.). The response rate was very low, which means the potential for non-response bias is significant. The sample size was small, so the estimates will not be very precise. The study consisted of adults only. Survey methods involving a visit to recruit participants and to perform measurements were not tested, because they were assessed as not cost-effective within available budgets for Phase II.

Future Research

Future research should conduct a personal magnetic-field exposure survey for a large sample (e.g., 1000 persons), including people under 18.

Summary

Phase 1 of the project, consisting of measurements for 200 randomly selected adults, has been completed. Protocols for Phase 2 have been developed and implemented on a larger population. Analysis of the PE data from Phase 1 indicates a geometric mean PE exposure of 1.02 mG. Exposures were affected by several residence characteristics including residence type, proximity to an overhead power line, and residence size.

Tasks: Phase II

1000-Person Survey

The objective of this project is to characterize personal magnetic-field exposure of the general population, by performing personal-exposure copy measurements for a sample of the population. The project is in two phases. Phase I was designed to develop survey methodologies and to conduct a small scale survey. Phase II consisted of a large scale survey using the methodology developed in Phase I. A little more than 1000 people participated in the survey of personal exposure for a 24-hour period. The protocol of the survey consisted of the following steps:

1. Telephone numbers were randomly selected using list-assisted RDD methodology.
2. An introductory letter was sent to all persons corresponding to the selected numbers.
3. The letters were followed up by telephone calls. Calls were also made to households that were not sent an introductory letter. The respondent was interviewed in order to select and recruit a household member for possible participation in the survey.
4. A Consent Form and a letter that illustrated the reasons and modality of the survey were sent to all the people who had agreed to participate.
5. The Consent Form was to be signed by the participants (or their parents or guardians) and returned before measurements could be performed.
6. Upon return of the signed Consent Form, the participants were sent a package containing a personal meter, the instructions for the use of the meter, a small diary to be used to write the type of activities performed, a questionnaire, and a $50 check for compensation for participating in the study. The personal exposure meter was of the size of a pager and could be clipped to a belt or placed in a pocket. For infants and toddlers, the meter was to be placed inside a teddy bear, to be worn as a backpack or kept near them for the day of the measurements.
7. The participants wore or kept the meter with them for 24 hours from the moment they first activated the meter. Magnetic-field values were recorded every 0.5 seconds. Summary statistics were stored in the meter’s memory every 10 minutes. The participants recorded the time when certain activities (at home not in bed, at home in bed, travel, work, or school) started or ended. After 24 hours of measurements, the meter was mailed back.
8. The meter’s data were transferred to a computer file. The information from the diary and from the questionnaire was transcribed in a computer database. The magnetic-field exposure for the entire 24 hours was calculated using a special software developed for the meter. The meter’s calibration was checked and the meters were prepared for new participants. A letter was sent to the participants with the results of their individual measurements.
9. The data from the meters, diaries, and questionnaire were analyzed.

The PE measurements began in November 1997 and were completed on April 3, 1998. In total, a little more than 1,000 meters with usable data were returned. Overall, 3867 households were contacted: 1796 persons were recruited by telephone, 1718 persons were sent a Consent Form to sign, and 1048 persons returned a signed Consent Form and were sent a meter. Based on the time and event data in the activity diary, the measurements in each data file were partitioned into the following categories: at home not in bed, at home in bed, at work, at school, during travel, and other. A variety of measures of the magnetic field were extracted for each subject and for each type of activity, including time spent for the activity, mean, standard deviation, geometric mean, geometric standard deviation, minimum and maximum, various percentiles from 1st to 99th, time spent above various field thresholds (from 0.5 to 64 mG), number of sudden field changes, length of time with constant field, and an index of intermittence.

In order to generate representative sample estimators of the general population, each participant was assigned a weight that takes into account the chance of selection of the person in the sample, and that can be interpreted as the number of persons in the population that the sample person is "representing." The estimated distribution of the 24-hour magnetic field for the U.S. population is shown in Table 4. The parameters of the distribution are shown in Table 5.

Table 4: **Estimated Percentage of People with 24-Hour Average Magnetic Field above Given Values** (results based on data from 853 of the little more than 1000 people surveyed)

24-Hour Average	Percentage of Population with Field Equal to or Exceeding Given Value
0.0 mG	100.00%
0.5 mG	77.20%
1.0 mG	44.40%
2.0 mG	14.70%
3.0 mG	5.87%
4.0 mG	3.33%
5.0 mG	2.40%
7.5 mG	0.45%
10.0 mG	0.41%

Table 5: Personal Exposure Survey - Descriptive Statistics of the Distribution of 24-Hour Average Magnetic Fields (results based on data from 853 of the little more than 1000 people surveyed)

Parameter of the Distribution of 24-Hour Average Fields	**Result**	**Parameter**	**Result**
Mean	1.26 mG	**Minimum**	0.07 mG
Standard Deviation	1.49 mG	1st Percentile	0.18 mG
Geometric Mean	0.90 mG	5th Percentile	0.26 mG
Geometric Standard Deviation	2.17	10th Percentile	0.37 mG
Median	0.88 mG	25th Percentile	0.52 mG
		50th Percentile (**Median**)	0.88 mG
		75th Percentile	1.47 mG
		90th Percentile	2.36 mG
		95th Percentile	3.26 mG
		99th Percentile	6.08 mG
		Maximum	25.7 mG

Participants were asked to keep a diary of their activities so that magnetic-field exposure could be evaluated not only for the total 24-hour period but also for different types of activities. The results for different activities are shown in Table S.3.

Table 6: Descriptive Statistics for Different Activity Periods

Parameter	Home not in Bed	In Bed	Work	School	Travel	24-Hour
Number of Participants with Valid Data	852	839	441	106	644	853
1st Percentile	0.09 mG	0.01 mG	0.16 mG	0.09 mG	0.18 mG	0.18 mG
5th Percentile	0.19 mG	0.08 mG	0.24 mG	0.16 mG	0.32 mG	0.26 mG
10th Percentile	0.27 mG	0.11 mG	0.33 mG	0.30 mG	0.42 mG	0.37 mG
25th Percentile	0.43 mG	0.23 mG	0.61 mG	0.41 mG	0.67 mG	0.52 mG
50th Percentile	0.73 mG	0.49 mG	1.01 mG	0.69 mG	0.97 mG	0.88 mG
75th Percentile	1.41 mG	1.22 mG	1.85 mG	1.10 mG	1.48 mG	1.47 mG
90th Percentile	2.63 mG	2.41 mG	3.40 mG	1.65 mG	2.29 mG	2.36 mG
95th Percentile	3.82 mG	3.55 mG	5.00 mG	1.92 mG	2.80 mG	3.26 mG
99th Percentile	8.80 mG	8.05 mG	10.6 mG	3.32 mG	4.68 mG	6.08 mG
Mean	1.27 mG	1.11 mG	1.79 mG	0.88 mG	1.24 mG	1.26 mG
Standard Deviation	1.72 mG	2.10 mG	3.13 mG	0.70 mG	0.99 mG	1.49 mG
Geometric Mean	0.80 mG	0.52 mG	1.09 mG	0.69 mG	0.99 mG	0.90 mG
Geometric Standard Deviation	2.52	3.52	2.49	2.06	1.96	2.17

The following conclusions could be drawn from the 1000-person sample.

1. The distribution of the average fields during a 24-hour period for the population of the U.S. is estimated to be log-normal with a geometric mean of 0.90 mG (95% CI from 0.85 to 0.96 mG) and a geometric standard deviation equal to 2.17 (95% CI from 2.08 to 2.27).
2. It is estimated that 14.7% (95% CI from 12.1% to 17.8%) of the U.S. population is exposed to a 24-hour average field exceeding 2 mG, 5.9% (95% CI from 4.2% to 8.2%) to a field exceeding 3 mG, 2.4% (95% CI from 1.49% to 3.9%) to a field exceeding 5 mG, and 0.41% (95% CI from 0.19% to 0.94%) to a field exceeding 10 mG.
3. About 26% of the people spend more than one hour at fields greater than 4 mG, and about 9% of the people spend more than one hour at fields greater than 8 mG.
4. About 2% of the people experience at least one gauss (1000 mG) during a 24-hour period.
5. The largest average fields (experienced by a few percentage of the people) were recorded during the period “at work.” The lowest average fields were recorded during the period “at home, in bed.” The average field “in school” exceeded 2 mG for about 3% of the students, while the field “at work” exceeded 2 mG for about

22% of the workers, and the field "at home" exceeded 2 mG for about 15.5% of the people.

6. For the periods "at work," the distribution of the average magnetic fields had the largest geometric mean for the service occupations (1.75 mG); followed by the electrical occupations (whose data, however, were few) with 1.17 mG; technical, sale, and administrative support occupations with 1.13 mG; managerial and professional specialty occupations with 1.05 mG; precision production, craft and repair occupation, and operators, fabricators, and laborers with 0.95 mG; and farming, forestry, and fishing occupations with 0.51 mG. The geometric standard deviation of the "at work" distribution of average field is significantly larger than for the distribution of the 24-hour period averages, meaning that some people at work are significantly more exposed than in other situations.
7. Very little difference in 24-hour average magnetic field was found between men and women (geometric mean 0.90 mG versus 0.91 mG). The largest geometric mean among age groups was found for working-age people (geometric mean = 0.97 mG), followed by retirement-age people (0.83 mG), school-age children (0.78 mG), and pre-school children (0.59 mG). Little difference was found among different regions of the U.S.. The largest geometric mean was found for the Northeast (0.96), followed by the West (0.96), the South (0.90), and the Midwest (0.83).
8. The following parameters appear to affect the distribution of exposures at home: residence type, residence size, type of water line, and proximity to an overhead power lines. The lowest exposure at home was measured for people living in mobile homes, followed by single family residences. Duplexes and apartments correspond to the largest exposures. The highest exposures at home are in smaller houses and in houses with metallic rather than plastic pipes. The exposure at home tends to increase as the distance to the nearest overhead line decreases. Proximity to three-phase electric power distribution and transmission lines corresponds to larger exposures than proximity to other types of lines or no line at all.
9. In addition to the statistical accuracy, there are other reasons why the results must be interpreted cautiously. The survey did not cover non-telephone households, military personnel, nursing homes, hospitalized people, people in prison, and any other institutionalized people. The response rate was very low and there is the potential for a significant non-response bias. The strength of the survey is in the random selection of the participants. The response rate, although low, was relative uniform across the age groups, gender, and regions of the participants. The survey is the first significant study that quantifies the exposure of the general population for the entire day, not only for the time spent in one's residence but also for the time a person is outside the home, working, in school, traveling, or performing other activities.
10. Despite its limitation, the survey provides data for an assessment of the number of people at risk, should researchers one day be capable of defining risk in terms of some of the quantities measured during this survey. The survey provided data not

only regarding the 24-hour average magnetic field, but also data on the time above defined field values, on the length of time with constant field, on the number of sudden field changes, and on the magnetic-field values during different types of activities.

Study Limitations

In addition to the issue of statistical accuracy, there are other reasons why the results must be interpreted cautiously. The survey did not cover non-telephone households, military personnel, nursing homes, hospitalized people, people in prison, and any other institutionalized people. The response rate was very low, and there is the potential for a significant non-response bias. The strength of the survey is in the random selection of the participants. The response rate, although low, was relative uniform across the age groups, gender, and regions of the participants. The survey is the first significant study that quantifies the exposure of the general population for the entire day, not only for the time spent in one's residence but also for the time a person is outside the home, working, in school, traveling, or performing other activities.

Areas for Future Research

Investigate the variability of personal exposure from day to day, the effect of the day of the week (weekday versus weekend), and seasonal effects for different regions of the U.S. Perform magnetic-field exposure surveys in other countries in order to assess relative risk among countries. Perform more detailed magnetic-field exposure measurements for people whose occupation classification has shown the highest magnetic-field values during the 1000-people survey and for other occupations known or suspected to correspond to higher exposures.

Summary

The second and last phase of the project, consisting of measurements of 24-hour personal magnetic-field exposure of 1000 people randomly selected within the U.S., has been completed. Exposure estimates for the general populations were made from the data collected. Detailed results of the survey of 853 people are presented in an Interim Report. The results of the survey of all the 1000 people will be presented in the Final Report. The data were entered in a database, which will be available to researchers to perform any further analysis that may be needed.

EMF RAPID Engineering Project #7:
Development of Field Exposure Prediction Models

Purpose and Focus

Project #7 sought to develop a general exposure model and demonstrate the technique for estimating magnetic-field personal exposure (PE) for individuals or groups.

Development of Method

The model employs exposure estimates for four environments (home, school, work, other); for four classes of subjects by age (preschoolers, children, adults, and seniors); and for two locales (urban/rural). It combines time/activity pattern information with PE, area, and/or magnetic-field source information to estimate personal exposure. Actual or estimated time/activity pattern information can be used.

Interviewers administer questionnaires to individuals or experts to obtain subject characteristics and estimated time/activity information. The questionnaire specifically targets time/activity information germane to environments, EMF exposure components, and presence or use of appliances and tools. Measured and/or estimated magnetic-field information can be combined in the model.

Contributions to exposure fall into three categories: (1) baseline exposures, (2) exposure components related to activity and/or location, and (3) field sources such as appliances and tools. The model specifies these exposure contributors for each of four environments: home, school, work, and other. Baseline exposures are defined so that exposure components and field sources generally increase estimated exposures.

The project demonstrates computational models that address three field parameters requiring different computational algorithms: time-weighted-average field (TWA), peak-field, and harmonic-field exposures.

- The TWA model (a traditional measure) requires that both the field level and time associated with environments, activity/locations, and sources be known.
- Modeling peak-field exposure (maximum exposure) requires knowledge about activity/locations and/or presence of sources.
- Estimating exposure to harmonics is difficult because there is so little data on harmonic fields. Consequently, this model will be less quantitative, with harmonic-field exposures expressed in terms of the percentage of time that harmonic fields may be present.

Sources are characterized by field levels at a distance determined by typical use. Estimates of baseline exposures, exposure components, and field sources were obtained from the literature, especially that of other RAPID projects. The exposure model is capable of computing estimates of either contemporaneous or historical exposure estimates. Point estimates or probability distributions can be assigned to the input variables, yielding point estimates or distributions for the exposure estimates.

The demonstration models were developed using commercial spreadsheet software; however, they can readily be implemented on a variety of hardware and software platforms. The model can also be easily adjusted to accommodate new data or alternative assumptions.

The questionnaire is being tested in pilot studies. Modeled exposures will be compared with measured exposures from these pilot studies.

The investigators concluded that no single approach to modeling EMF exposure is appropriate. Different approaches, algorithms, and assumptions may be appropriate between and within environments and for different sources. Subject attributes (e.g., age, gender) may affect the time spent in environments, activities, and near sources, but these attributes are not likely to affect baseline field levels. The use of a Monte Carlo simulation program to introduce distributions for selected field and time variables greatly enhances the value of the model.

Study Limitations

The demonstration of the model used probability distributions for field levels that were, in many instances, arbitrary. The empirical basis for combining fields associated with various EMF factors and for assigning probability distributions to inputs for the model is not strong. A limited number of sources is included in the model and, therefore, in the questionnaire. Except for electric blankets, only point estimates have been introduced for sources. The investigators used a subjective assignment of distance for estimating TWA and peak exposures.

Areas for Future Research

Additional investigation of probability distributions for field levels and their assignment would be useful. The model could readily include additional sources or incorporate a more sophisticated assignment of exposure values in the future.

Activity categories used in diaries and questionnaires are not necessarily linked to EMF exposures. Development of activity categories and questions specific to EMF exposures could reduce uncertainty in model predictions.

Summary

Baseline exposures were established for each of the eight groups (four age groups, urban and rural) in the four environments. Exposure components and sources were identified and assigned field values in the four environments. PE measurements are the preferred source for estimating baseline exposures and exposure components. Field values for sources were based on measurements reported in the literature and assumed distances during use. Criteria for inclusion of exposure components of sources in computations have been established. For example, for TWA estimates, only components with exposures (field multiplied by time) that exceed baseline exposures by a pre-selected percentage are included. Computational algorithms have been completed for the three demonstration exposure parameters. The final report for this project is in preparation.

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EMF RAPID Program Engineering Project #8: Evaluation of Field-reduction Technologies

Purpose and Focus

This project evaluates field-reduction techniques with a goal of providing information to help decisionmakers consider essential questions centered on the potential for and ways to reduce fields. Until the proposed power-frequency magnetic-field health effects hypotheses are either proved or disproved, no scientific basis for defining safe human exposure thresholds will exist. Long-term planners must nonetheless ask whether it would be technically and economically possible to modify the use of electric power if magnetic fields were ever linked to adverse health.

Tasks and Approach

The project examines field-reduction methods for a variety of magnetic-field sources. These include the following:

- transmission lines,
- distribution lines,
- substations,
- building wiring,
- appliances and machinery, and
- transportation systems.

There are at least five magnetic-field-reduction methods. These include the following:

- minimizing magnetic fields when current-carrying conductors are matched with appropriate return conductors,
- placing opposing current pairs as close together as possible,
- splitting currents,
- decreasing magnetic fields via distance from the sources, and
- reducing current and thus reducing magnetic fields.

Within each category, magnetic-field-reduction methods are evaluated, based on their effectiveness, cost, environmental impact, and safety impact. The report focuses on power-frequency magnetic fields because these have been the focus of most of the recent health effects research.

One or more “problem” sources are identified that would be exceptionally difficult or expensive to modify into low-field versions if exposure limits were imposed. They include the following:

(1) transmission lines operating at voltages of 500 kV or above;
(2) unbalanced resultant (zero sequence) current on distribution lines;
(3) transmission line substation connections at 500 kV or above;
(4) vaults, buses, and feeders in buildings;

(5) industrial welding and metal melting processes; and
(6) most types of electric railway systems.

Transmission Lines

A case-study approach was used to compare magnetic fields, electric fields, and life cycle costs of various transmission line designs. Both “rural” and “suburban” designs were examined within each of four voltage categories (69 kV, 115 kV, 230 kV, and 345 kV). Rural-only designs were examined at 500 kV and 765 kV.

Several magnetic-field-reduction methods were considered. These included the following:

- compaction,
- phase splitting,
- higher voltage lines,
- shielding provided by underground pipe-type cables, and
- line-side passive cancellation loops.

The analysis showed that transmission-line life-cycle costs would increase sharply if magnetic-field exposure limits were set at 5 mG or 2 mG for publicly accessible areas.

- At 69 kV and 115 kV, life-cycle costs could increase by as much as 20% to meet a 20-mG standard and could double or triple to meet a 2-mG standard.
- At 230 kV, costs could increase by as much as 50% for 20 mG and triple or quadruple for a 2 mG limit.
- Costs for a 345-kV line would triple or quadruple to meet a 20-mG exposure limit. (See Table A-12, below.)
- No 500-kV options were identified that could meet a 50-mG or lower exposure limit; no 765-kV options were found that could meet a 100-mG or lower limit on the right-of-way. A series-capacitor-compensated cancellation loop might be effective for 500-kV and 765-kV edge-of-right-of-way field limits, however.

Table A-12: Transmission-line Magnetic-field-reduction Summary (selected cases)

Voltage	<50 mG Type	Live-Cycle Cost Multiplier	<20 mG Type	Life-Cycle Cost Multiplier	<5 mG Type	Life-Cycle Cost Multiplier	<2 mG Type	Life-Cycle Cost Multiplier
69 kV (72 MVA) Rural	Split-6	1.13	Split-6	1.13	Split-6 Suburban	1.48	UG HPGF Pipe	2.67
69 kV (72 MVA) Suburban	Delta	1.00	Split-6	1.23	Split-6	1.23	UG HPGF Pipe	2.21

Voltage	**<50 mG Type**	**Live-Cycle Cost Multiplier**	**<20 mG Type**	**Life-Cycle Cost Multiplier**	**<5 mG Type**	**Life-Cycle Cost Multiplier**	**<2 mG Type**	**Life-Cycle Cost Multiplier**
115-kV (120 MVA) Rural	Delta Cpct.	0.96	Split-6 Cpct.	1.18	Split-6 Cpct. Suburban	1.56	UG HPGF Pipe	2.78
115 kV (120 MVA) Suburban	Delta	1.00	Delta Cpct.	0.97	Split-6 Cpct.	1.24	UG HPGF Pipe	2.22
230 kV (239 MVA) Rural	Split-6 Cpct.	1.16	Split-6 Cpct. Suburban	1.48	UG HPFF Pipe	3.80	UG HPFF Pipe	3.80
230 kV (239 MVA) Suburban	Delta	1.00	Split-6 Cpct.	1.18	UG HPFF Pipe	3.01	UG HPFF Pipe	3.01
345 kV (717 MVA) Rural	230 kV Split-6 Cpct. Suburban	1.54	UG HPFF Pipe	3.88	UG HPFF Pipe	3.88	UG HPFF Pipe+?	3.88+?
345 kV (717 MVA) Suburban	230 kV Split-6 Cpct.	1.19	UG HPFF Pipe	2.98	UG HPFF Pipe	2.98	UG HPFF Pipe+?	2.98+?

Underground pipe-type cables provide the lowest transmission-line magnetic fields, but are not commercially available for line voltages exceeding 345 kV. Their use would almost certainly be required to meet 2-mG standards. Six-wire and five-wire split-phase lines (the lowest-field overhead conductor designs) could probably meet 5-mG standards at 115 kV and below. The taller towers and shorter spans of the suburban overhead transmission lines studied at 345 kV and below offered much lower peak magnetic and electric fields than their rural counterparts. The effect was less significant outside the right-of-way.

Unbalanced resultant (zero sequence) currents are usually the most significant magnetic-field source outside a transmission line right-of-way. If low magnetic-field levels were mandated, unbalanced current would have to be minimized throughout the transmission network. This action would entail balancing the line loading at transmission substations, transposing transmission line conductors, and adding low-impedance shield wires to “attract” zero sequence current.

Distribution Lines

The magnetic fields, electric fields, and life cycle costs of various distribution-line designs were also examined during the project. Both “rural” and “suburban” designs were modeled for 7.6-kV single-phase, 13.2-kV three-phase, and 34.5-kV three-phase categories. Several magnetic-field reduction concepts were evaluated, including compaction, phase splitting, and the use of higher voltage (same load) to reduce current.

For balanced phase-current conditions, low-field distribution line life-cycle costs were predicted to increase significantly only for presumed exposure limits of about 5 mG or less. Costs increased as much as 40% for a 2-mG limit at 7.6 kV and 13.2 kV, for which tall compact and split-phase Hendrix cable designs could be used. Life-cycle costs for 34.5 kV lines were predicted to increase by 50% to 100% to meet a 2-mG limit, accomplished with a split-phase Hendrix cable design. Heavily loaded distribution lines would have to be shielded, perhaps by underground conduit, to meet a 2-mG limit.

Underground duct and direct burial designs produced the highest magnetic fields at 13.2 kV and 34.5 kV. The underground duct designs nearly triple the baseline design life-cycle costs. See Table A-13, below.

Unbalanced resultant (zero sequence) current is often the most significant source of distribution-line magnetic fields. If very low magnetic-field exposure limits were mandated, control of zero sequence current would be necessary at every point in the distribution network. This significant challenge would require rethinking not only line-design methods, but also broader network-scale issues such as grounding methods, distribution voltage selection, and transformer sizing.

Table A-13: Distribution-line Magnetic-field Reduction Summary (selected cases)

	<50 mG		<20 mG		<5 mG		<2 mG	
Voltage	Type	Life-Cycle Cost Multiplier	Type	Life-Cycle Cost Multiplier	Type	Life-Cycle Cost Multiplier	Type	Life-Cycle Cost Multiplier
7.6 kV (0.76 MVA) Rural	Standard	1.00	Standard	1.00	Tall Cpct.	1.12	Tall	1.12
7.6 kV (1.52 MVA) Suburban	Standard	1.00	Standard	1.00	UG Direct Bury	1.08	Cpct.	1.12+?
13.2 kV (6.86 MVA) Rural	Cross Arm	1.00	Cross Arm	1.00	Split-6 Cross Arm	1.15	Tall Cpct.+?	1.38
13.2 kV (13.7 MVA) Suburban	Cross Arm	1.00	UG Direct Bury	1.05	Split-6 Hendrix	1.32	Split-6 Hendrix	1.32

34.5 kV (17.93 MVA) Rural	Cross Arm	1.00	Delta	1.05	Hendrix Cable	1.31	Split-6 Hendrix	1.55
34.5 kV (35.85 MVA) Suburban	Cross Arm	1.00	Delta	1.08	Split-6 Hendrix	1.45	?	?

Substations

Most of the magnetic field at a substation perimeter fence stems from transmission and distribution lines entering or leaving the facility. The need to build low-field transmission- and distribution-line segments at the station entrance would heavily influence the feasibility and cost of reducing substation magnetic fields. Field-reduction methods and life-cycle costs of these line segments would be similar to those listed for transmission and distribution lines. Few, if any, methods are available to allow 500-kV and 765-kV lines to meet exposure limits below 100 mG.

The cost of a “low-field” substation design would also include the cost of expanding the perimeter fence or wall, if needed. More difficult to predict would be the cost of reducing substation worker exposures. Potential methods for reducing worker exposures include shielding, especially with metal-clad switchgear or gas-insulated substation buses, and remote operation and maintenance.

Customer-side Power Distribution

Many magnetic-field sources are found on the customer side of the electric-utility service connection. These include customer-owned power-distribution equipment such as transformers, switchgear, buses, feeders, service panels, and general wiring. Grounding methods at and beyond the service connection can also affect magnetic fields if stray return current paths are created. Residential and small commercial environments use mostly single-phase sources. Larger commercial and industrial environments use mostly three-phase sources.

Field-reduction methods include rewiring to correct on-premises stray return currents and current loops; installing net current control devices to stop off-premises stray currents; and using rigid metal conduit or flat plate shielding for buses, feeders, branch circuits, lighting panels, and transformer vaults.

Only a few sources, such as transformer vaults and heavily loaded buses and feeders, would require attention if a 100-mG exposure limit were specified. At 5 mG or less, all sources would require attention. The greatest cost impacts would occur if vaults, buses, and feeders had to meet a 5-mG or 2-mG exposure criterion. Such installations could at least double in cost. Some office-building owners have already spent tens to hundreds of thousands of dollars to reduce computer display interference problems by installing magnetic-field shielding.

Appliances

The primary sources of magnetic fields from end-user appliances are resistive heating elements, motors, transformers and coils, and power cords and wiring. Field-reduction methods for these include use of split return or bifiliar heating elements, replacement of inexpensive motors with heavier-duty motors, use of toroidial transformers and coils, installation of shielding for most sources, and conductor compaction for wiring,

The lowest existing magnetic-field emission guideline was established for computer video display terminals (VDTs) by the Swedish government in 1991. That standard, called MPR2, requires VDT magnetic fields to be less than 250 nT (2.5 mG) 50 cm (20 in) from the monitor in the 5 Hz-2 kHz frequency range and less than 25 nT (0.25 mG) in the 2 kHz-400 kHz frequency range. Most new computer monitors are designed to meet the MPR2 standard, since manufacturers have found it possible to meet the standard with little added cost. See Table A-14, below.

No magnetic-field guidelines apply to electric blankets, but some manufacturers have altered their designs to reduce magnetic fields. No other low-field appliance examples are known.

The experience of video-display manufacturers shows that some appliances and machines can be modified at little cost to meet low magnetic-field exposure limits. How far this low cost trend extends to other appliances and machines is unknown, because almost no effort has been expended in this area. Without question, however, some industrial welding and electrically heated metal melting processes would present extraordinary design and cost challenges if low field limits were imposed.

Table A-14: Appliance and Machinery Magnetic-field Reduction Summary

Source Type	<50 mG Method	Est. Cost Multiplier	<20 mG Method	Est. Cost Multiplier	<5 mG Method	Est. Cost Multiplier	<2 mG Method	Est. Cost Multiplier
Appliance Resistive Heating Elements	No Change	1.00	Split Return or Bifiliar	1.00-1.50	Split Return or Bifiliar	1.00-1.50	Split Return or Bifiliar	1.00-1.50
Industrial Resistive Heating Elements	Split Return or Bifiliar	1.00-1.50	Split Return or Bifiliar	1.00-1.50	Split Return or Bifiliar+?	1.00-1.50+?	Split Return or Bifiliar+?	1.00-1.50+?
Inexpensive Fractional HP Motors	Shield or Replace	1.00-2.00	Shield or Replace	1.00-2.00	Shield or Replace	1.10-2.00	Shield or Replace	1.10-2.00
Heavier-Duty Motors	No Change	1.00	Shield or Upgrade	1.00-1.50	Shield or Upgrade	1.00-1.50	Shield or Upgrade	1.00-1.50

Appliance Transformers and Coils	No Change	1.00	Shield or Toroid	1.00-1.50	Shield or Toroid	1.00-1.50	Shield or Toroid	1.00-1.50
Industrial Transformers and Coils	Shield or Toroid if needed	1.00-1.50	Shield or Toroid	1.00-1.50	Shield or Toroid	1.00-1.50	Shield or Toroid	1.00-1.50
Appliance Power Cords and Wiring	No Change	1.00	No Change	1.00	Conductor Twisting/ Spacing	1.00-1.10	Conductor Twisting/ Spacing	1.00-1.10
Industrial Power Cords and Wiring	No Change	1.00	Conductor Twisting/ Spacing	1.00-1.10		1.00-1.10		1.00-1.50
High-Field Industrial Machines (Arc Furnaces, welding, etc.)	Remote Operation ?	1.50+?	Remote Operation ?	1.50+?	Remote Operation ?	1.50+?	Remote Operation ?	1.50+?

Transportation Systems

Power-frequency magnetic-field exposure limits could substantially affect electric railways and other transportation systems. For electric railways, edge-of-right-of-way exposure limits would require changes like those required for transmission and distribution lines. Exposure limits defined for rail passengers would be much more difficult to meet.

Magnetic-field reduction methods might include the following:

- use of DC currents,
- use of third rail or dual overhead trolley bus type feed systems for lower-speed trains,
- use of single-ended autotransformer feeds for high-speed trains,
- use of higher voltages, and
- use of shielding.

The uncertain life-cycle costs of these options would have to be weighed against the costs of abandoning electrification in favor of high-speed diesel or turbine motive power.

Study Limitations/Areas for Future Research

The investigators had access only to data on existing technologies and/or published research reports. Consequently, important work in progress under EPRI sponsorship and proprietary information were unavailable for consideration and inclusion.

The estimates of costs for powerline field management are based on standard right-of-way widths. Adjustments for land costs are available in Volume II of the report.
Incorporate recent work and new technologies into similar cost estimates.

Summary

Lifetime cost estimates were developed for reducing magnetic fields from six source types. The relative cost depends strongly on the source type and the selected field criterion.

Transmission lines: Low-field rural transmission line costs increase more than low-field suburban costs. Transmission life-cycle costs increase sharply at 5 mG and 2mG for 69-kV, 115-kV, and 230-kV designs. 345-kV line costs increase significantly below 20 mG for suburban designs and below 100 mG for rural designs. No 500-kV options are available for 50 mG or less; no 765-kV options are available for 100 mG or less.

Distribution lines: Low-field distribution line life-cycle costs increase significantly only for field limits of about 5 mG or less. Distribution-line cost multipliers increase with voltage. No 34.5-kV suburban design option was available for the 2-mG threshold.

Substations: Most of the magnetic field at a substation perimeter fence is from transmission and distribution lines entering the facility. The feasibility and cost of limiting public exposure to substation magnetic fields would be heavily influenced by the need to build low-cost transmission/distribution-line segments at the station entrance. More difficult to predict would be the cost of reducing substation worker exposures. Potential methods for reducing worker exposures include shielding (e.g., metal-clad switchgear or gas-insulated substation buses), and remote operation and maintenance.

Customer-side power distribution: Meeting a standard with new construction would be easier than retrofitting an existing installation. Only a few sources (e.g., transformer vaults and heavily loaded buses and feeders) would require attention if a 100-mG exposure limit were specified. At 5 mG or less, all sources would require attention. The greatest cost impacts would occur if vaults, buses, and feeders had to meet a 5-mG or 2-mG exposure criterion.

Appliances and machinery: Magnetic-field limits would depend on limit values and how exposure limits were defined. Most appliances and machinery magnetic fields drop off quickly. However, exposure limits defined for all points and near an appliance or machine could be extraordinarily difficult to achieve.

Electric railway: Power-frequency magnetic-field exposure limits could substantially affect electric railways and other transportation systems. Impact would depend on values and definition, as with appliances. Edge-of-right-of-way limits would require changes like those for transmission lines. Exposure limits defined for rail passengers would be more difficult to meet.

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