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Potential Health Effects of Low Frequency Electromagnetic Fields Due to Maglev and Other Electric Rail Systems

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13. ABSTRACT (Maximum 200 words)

The safety of magnetically-levitated (maglev) and high-speed rail (HSR) trains proposed for use in the United States is the responsibility of the Federal Railroad Administration. There are concerns for physical safety associated with equipment operation and high-voltage currents, and for potential adverse health effects on transportation workers and the public from the electric and magnetic fields (EMF) produced in the Extremely Low Frequency (ELF) range (3-3,000 Hz). This report outlines research on the biological and health effects of EMF most relevant to fields generated by maglev and HSR systems. Among the conclusions are: epidemiologic results suggest a low-level health risk for power-line frequency ELF EMF which is, at present, the most relevant risk to ascribe to maglev systems; bioeffects may occur at specific window frequencies and intensities; of effects ascribed to EMF, the most convincing are altered circadian rhythms of melatonin secretion, modulation of transmembrane calcium transport, slight increases in the risks for some rare cancers, and mild behavioral disturbances; occupational categories used as the basis for epidemiologic studies need better definition in terms of the characteristics of EMF exposure; and, there is need to improve bioassay systems and test maglev-type fields on them.

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PREFACE

This final report has been prepared by the staff of Information Ventures, Incorporated, for submission to the U.S. Department of Transportation (DOT), Federal Railroad Agency (FRA), Volpe National Transportation Systems Center (VNTSC). It is an independent assessment of the current state of knowledge about the potential health effects of the low frequency electromagnetic emissions associated with maglev and other high-speed rail technology.

The primary authors of this report are William A. Creasey, D.Phil., and Robert B. Goldberg, Ph.D. Analysis of measurement data from the TR07 system, obtained from Electric Research and Management (ERM) and FRA, was performed by Kenneth R. Foster, Ph.D. of the Department of Bioengineering, University of Pennsylvania. The authors would like to thank, for guidance and review comments: Dr. Aviva Brecher, the Volpe Center EMF Research Program Manager and technical monitor for this project; Mr. Arne Bang, FRA Senior Manager of Special Programs, who sponsored this research; and Mr. Robert Dorer, the Volpe Center Manager of the High Speed Guided Ground Transportation Safety Program.

SYSTÈME INTERNATIONAL (SI) UNIT DEFINITIONS AND CONVERSIONS USED IN THIS REPORT

DISTANCE (ENGLISH-TO-SI CONVERSION):

1 inch (in)	= 2.54 centimeters (cm)	= 0.025 meters (m)
1 foot (ft)	= 30.5 centimeters (cm)	= 0.305 meters (m)
1 yard (yd)	= 91.4 centimeters (cm)	= 0.914 meters (m)
1 mile (mi)	= 1.61 kilometers (km)	= 1,610 meters (m)

ELECTRICAL QUANTITIES:

Electric Fields

1 Volt/meter (V/m)	= 0.01 Volts/centimeter (V/cm)
1 kiloVolt/meter (kV/m)	= 1000 Volts/meter (V/m)
1 kiloVolt/meter (kV/m)	= 10 Volts/centimeter (V/cm)

Magnetic Flux Densities (English-to-SI Conversion)

10,000 Gauss (G)	= 1 Tesla (T)
10 milliGauss (mG)	= 1 microTesla (μT)
1 milliGauss (mG)	= .1 microTesla (μT)
0.01 milliGauss (mG)	= 1 nanoTesla (nT)

Electromagnetic Frequency Bands

1 cycle per second	= 1 Hertz (Hz)
1,000 cycles per second	= 1 kiloHertz (kHz)

Ultra Low Frequency (ULF) Band	= 0 Hz to 3 Hz
Extreme Low Frequency (ELF) Band	= 3 Hz to 3 kHz
Very Low Frequency (VLF) Band	= 3 kHz to 30 kHz
Low Frequency (LF) Band	= 30 kHz to 300 kHz

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1. EXECUTIVE SUMMARY

The introduction of new large-scale electronic technology such as magnetic levitation (maglev) rail transport raises concerns over possible human health effects resulting from electromagnetic field (EMF) exposures for workers and the general public. In preparing this report, the staff of Information Ventures, Inc., have reviewed the scientific literature on EMF bioeffects for the Department of Transportation's Volpe National Transportation Systems Center (VNTSC) to identify studies which might be relevant to maglev fields. This report describes those studies which might provide some basis for making preliminary recommendations on the possible human health impact of this technology.

1.1 THE PROBLEM OF ELF EMF RISK ASSESSMENT

Traditional risk assessment applied to maglev EMF exposures would involve several steps: (1) defining a hazard, (2) establishing a dose-response relationship for that endpoint, (3) establishing the exposure from the new technology, and (4) projecting the potential health impact. Well-defined EMF hazards do exist (such as electric shock, pacemaker interference, and burns), but these require fields of much higher intensity than personnel are likely to encounter with maglev. There is, however, some concern over possible hazards from chronic exposure to relatively weak extremely low frequency (ELF) magnetic fields. Endpoints of concern include several types of cancer, reproductive problems, and behavioral effects. The epidemiologic studies which have raised these concerns are inconclusive and difficult to interpret for reasons that have been well discussed in the literature. There have been a few large-scale animal screening studies, and these have shown little effect of ELF EMF. Animal studies evaluating the ability of ELF magnetic fields to promote cancer in combination with chemical initiators of cancer, or to copromote cancer in combination with initiators and low levels of chemical promoters, have been conducted only in the last few years. The few studies which have been completed to date have produced conflicting results. In at least one case, there is strong evidence for ELF EMF as a copromoter, but the study has not yet been replicated. At the present time, there is little basis therefore for quantitative risk assessment.

Nevertheless, it is possible to compare the magnetic field exposure from maglev with that associated with other systems. This provides a useful first approach in assessing the potential impact of maglev technology in relation to existing sources of EMF exposure. In addition, we have searched the literature for other relevant studies. These include epidemiologic studies of workers exposed to existing electric rail systems (who are also exposed to considerable ELF magnetic fields) and basic biological studies that might indicate possible mechanisms for hazard.

1.2 EXPOSURE ASSESSMENT OF THE TR07 MAGLEV TRAIN

The only detailed measurements of a maglev system available to us were made by Electric Research & Management, Inc. (ERM) at the Emsland Transrapid Test Facility, Germany. AC magnetic field emissions from the TR07 maglev system occur primarily in the ELF range (0-300 Hz) with more intermittent (transient) and intense exposures in the 2-45 Hz range than is typical of power frequency (50 or 60 Hz) exposures. Total ELF EMF field intensities are usually less than 100 mG at floor level and under 20 mG at head level for passengers, with occupational exposures slightly higher in intensity and richer in higher frequency components. The frequency components vary with vehicle speed. The DC magnetic field is within 400 mG of geomagnetic field levels at the maglev train floor, and within about 100 mG of ambient levels at head height. These levels fall well within existing international exposure guidelines in terms of time-averaged field intensity, the basis for current exposure standards.

1.3 EXPOSURE ASSESSMENT OF OTHER RAIL SYSTEMS

ERM has also completed detailed measurements of operating electrified rail systems including the French high-speed train a Grande Vitesse-Atlantique (TGV-A) which operates with 25 kV, 50 Hz AC power or (in different sections of track) 1500 V DC power; 25 or 60 Hz powered trains the Amtrak Northeast Corridor (NEC) and New Jersey Transit trains; and DC-powered trains operating on the Massachusetts Bay Transportation Authority (MBTA) system in the Boston area.

In general, the average time-varying magnetic field exposures in the coaches of AC-powered NEC systems are dominated by the power frequency and its odd harmonics. For the 25 Hz system, coach levels averaged approximately 130 mG, with maximum fields, at floor level, 3-5 times higher than the average. In the 60 Hz systems, power frequency magnetic fields were of lower intensity (19-52 mG average). Average magnetic fields in the locomotive cabs were 46 mG (25 Hz power) and 27-28 mG (60 Hz system). Unlike the TR07 maglev system, the frequency spectrum of these rail systems was dominated by the power frequency band and its odd harmonics, with very low ELF EMF intensities below power frequency.

On the French TGV-A system, DC magnetic fields in the DC-powered section averaged 913 mG (maximum 3.066 G) in the coaches, and AC fields in the 50 Hz sections averaged 31 mG (maximum 165 mG). Measurements made on DC-powered trains operating on the MBTA system in the Boston area indicated a similar levels of exposure. On board MBTA subway cars, the average static magnetic field intensity was 507 mG, with a maximum of 1446 mG at seat level. The predominant magnetic field frequency was DC, with some ELF components resulting from fluctuations in the DC field level and rectifier ripple in the DC power supplies. On the Mattapan High Speed Trolley, the average static magnetic field was 1501 mG (maximum 3.074 G) at floor level and averaged 517 mG (774 mG maximum) at seat height. ERM reports characterized the magnetic fields produced by these conventional electrified rail systems as similar to magnetic fields near many electrical appliances with varying load or intermittent use. Therefore, currently operating electric rail transportation systems expose workers and passengers to magnetic fields with similar intensity but much greater variability than fields associated with electric power transmission lines.

1.4 REVIEW OF THE RELEVANT EMF RESEARCH LITERATURE

Information Ventures staff prepared analytical summary abstracts of the diverse interdisciplinary EMF research literature which consistently include details of experimental design and results not commonly found in the author's abstract. This material was used to establish a unique computerized database, the *EMF Database*, which presently contains more than 13,000 analytical abstracts. This database served as the source of literature for this report.

Our review has considered three general classes of studies relevant to concerns raised by maglev: (1) epidemiologic and occupational health studies involving railway and other workers with exposures analogous to anticipated maglev exposures; (2) animal screening studies; and (3) basic studies of ELF EMF bioeffects which suggest a potential interaction with maglev fields.

1.4.1 Epidemiologic Studies

Very few epidemiologic studies have been restricted to railroad workers. Most studies have included rail workers among other "electrical workers," and the very limited data suggest they have a modest increase in cancer risk (approximately doubled) as reported by several authors for other occupational groups with presumed ELF EMF exposure. Behavioral changes, fetal loss and abnormalities, and altered circadian rhythms have also been reported after varied types of ELF EMF exposures, although most studies carried out in western nations have not confirmed the much more striking health and behavioral effects reported in the literature from the former Soviet Union. Interpretation of these reports is limited by small sample sizes, unreliable exposure estimates, and the possibility of confounding factors.

1.4.2 Animal Toxicology Studies

Few large scale animal toxicology studies have been completed using ELF EMF fields which include a magnetic field component. A number of animal studies are still in progress, including some that test for possible copromotional effects of ELF EMF in carcinogenesis experiments. Most of these studies have indicated no effect of 50 or 60 Hz magnetic field exposures, but a few have reported EMF-mediated increases in the rate of tumor growth and/or the number of animals with tumors. These results have not yet been replicated. Behavioral studies with baboons suggest possible stress and disruption of learning and task performance with chronic moderate ELF electric field exposure, and modification of the response by simultaneous exposure to ELF magnetic field components.

1.4.3 Animal and In Vitro Bioeffect Studies

ELF EMF bioeffects studies are much more diverse and harder to interpret in terms of potential health hazards. Studies are just getting underway to evaluate maglev-type fields directly. Low intensity 16 Hz magnetic fields have been reported to cause altered calcium flux in brain tissue. There are reports of altered mobility of diatoms, but other groups were unable to replicate their results. Disruption of the nocturnal rise in melatonin levels by a sudden inversion of the DC magnetic fields in rats and by exposure to 60 Hz AC magnetic fields in hamsters have been reported. Time-varying magnetic fields have been reported to produce teratological effects in early chicken embryos, although the response is not always replicated and the effects do not show a clear pattern related to dose. Finally, cells in vitro have shown transitory alterations in patterns of mRNA synthesis in response to AC magnetic fields at 45 and 60 Hz. The implications of these effects are unclear at present and thus any extrapolation to health risk for human populations is unwarranted.

1.5 GUIDELINES

A tabulation of existing guidelines regarding ELF EMF exposure is presented. Anticipated maglev and conventional electrified rail system exposures fall below the most conservative recommended levels of exposure. It should be noted, however, that these guidelines are based on established risks of shock and behavioral disruption and do not include limits to protect against possible long-term low-level effects.

1.6 CONCLUSIONS

A summary of the chief findings is presented, together with recommendations for areas meriting increased research emphasis.

2. INTRODUCTION

Electromagnetic fields (EMFs) have been associated with a broad range of subtle and overt biological effects, some of which have clear implications for human health. These effects can be roughly divided into higher intensity effects, usually of an acute nature, which are universally accepted hazards, and low intensity effects, which are the subject of considerable controversy within both the research and public policy communities. Obvious high intensity effects, such as risk of shock, burns, and hyperthermia from EMF of higher frequency (such as microwaves), are primarily engineering and occupational safety concerns, and fall beyond the scope of this report. Low intensity EMF effects, for the most part associated with EMFs of frequencies below 1 kHz, constitute a more complex problem for regulatory agencies, such as the Federal Railroad Administration, because the possible hazards are poorly defined; it is uncertain what are the most appropriate actions needed to mitigate any such effects; and the need to take any protective or regulatory action has not yet been clearly demonstrated.

The objective of this literature review is not to present a complete and comprehensive survey of all low intensity EMF bioeffects and their possible human health implications, but to make some tentative judgements as to which research is most relevant to possible health concerns raised by transportation systems, and what conclusions are possible, based on the research findings currently available. In order to be able to arrive at conclusions concerning potential human health consequences of exposure to EMF from magnetically-levitated (maglev) and other high-speed electric rail transportation systems, the following specific questions must be answered: (1) what information is currently available from epidemiologic studies and case reports to suggest that there are human health effects from exposure to the types of electromagnetic fields produced by existing rail transport systems; (2) what information is currently available to characterize EMFs produced by current and proposed rail transport systems and, for comparative purposes, other common sources of EMFs; and, (3) to the extent that such fields can be characterized, what experimental and epidemiological evidence is there which might suggest negative human health consequences from exposure to specific types of EMF produced by present and/or future transport systems? For clarity in evaluating the relevance of research results to human health risk issues and policy decisions, human studies are considered separately from whole animal and cellular studies. The final section of this report briefly presents some summary conclusions based on the evidence from both human epidemiologic and experimental approaches, and suggests some research areas which should be monitored closely, and others where further research is needed.

3. CLINICAL AND EPIDEMIOLOGIC STUDIES OF RAILROAD WORKERS AND OTHERS EXPOSED TO EMF ASSOCIATED WITH RAILROAD OPERATION

Few epidemiologic studies have focused specifically on railroad workers. Generally, conclusions are limited by the relatively small sample sizes in any study of such specific occupational categories, and restricted occupational groups are not usually studied unless a cluster of cases draws attention to a possible occupational association. As far as we can determine, no such cluster has been reported for rail workers.

A cross-sectional epidemiological survey was conducted by Baroncelli *et al.* (1986) of male workers in the "Electrical Devices" departments of railways in Italy who are occupationally exposed to ELF EMF from interconnection and conversion substations. Maximum levels of the electric field strength and of the magnetic flux density at 50 Hz were of the order of 5 kV/m and 150 mG, respectively. Exposure of subjects to electromagnetic fields was assessed and categorized by mean weekly duration of exposure to the maximum electromagnetic field strength: 1 h/week; 10 h/week; and 20 h/week. Health examinations were performed on 224 subjects in the 20 h/week exposure category, 153 subjects in the 10 h/week, 117 in the 1 h/week, and 133 in a zero-exposure category. General medical examinations and electrocardiographic, hematologic, and psychological evaluations were performed. There were no differences between the groups for any of the parameters examined. Similar conclusions were reached by Nakagawa *et al.* (1992) in a survey of standardized mortality rates (SMRs) among male Japanese National Railways workers over 40 years of age between 1968 and 1985. Overall, the SMRs for these workers (range 0.55-0.80) were below the national average, and for those specifically associated with electrical occupations, the SMRs for malignant neoplasms were the lowest of all six job categories (0.60 and 0.54 for electric train crews and power facility workers, respectively), and there were no deaths from leukemia among workers in electric power facilities.

Balli-Antunes *et al.* conducted a relatively large scale retrospective analysis of deaths from hematopoietic and lymphoid malignancies among Swiss electric railway engine drivers (Balli-Antunes *et al.*, 1990). Two occupational groups were used as controls: metal construction and machine building workers with similar chemical (solvent and lubricant) exposures; and technical personnel, exposed to a work environment different from drivers, but who resembled the study group more closely in socioeconomic characteristics. There was a small but significant ($p = 0.009$) increase in the SMR (171, 95% confidence interval (CI) 109-257) for the period 1969-1983, but comparison against the group of machine workers showed elevated mortality only after age 70, and the SMR at 108 (CI, 69-163) was not significantly increased. Since estimated voltage within the engine area is about 0.6 kV, producing a magnetic field strength of 100 A/m, or approximately 1.3 G, engine drivers are exposed to fields 2-3 orders of magnitude greater than electric transmission line workers. The authors considered their results as evidence against a leukemogenic effect of ELF EMF.

Results of a study of leukemia and brain tumors in Norwegian railway workers were reported recently by Tynes et al. (Tynes *et al.* 1993). In Norway, about half the rail lines are electrified (a 16.66 Hz, 11 kV system) while the remainder are not, allowing a direct comparison of similar

EMF-exposed and nonexposed occupational groups. A cohort of 13,026 railway line workers, outdoor station workers, and electricity workers were evaluated with national rural incidence rates and, in a nested case-control design, with similar nonelectrified rail system workers. The case series for this group was 52 leukemia and 39 brain cancer cases. The standardized incidence ratio for all cancers in the electric railway workers was lower than in the reference groups: men employed in electric railroad work had an odds ratio for leukemia (adjusted for smoking) of 0.7 and a brain tumor odds ratio of 0.87. In the oral presentation of this work, Tynes indicated that an attempt was made to estimate exposures for electric railway workers, and that these exposures averaged 19.7 μT (almost 200 mG), but varied greatly among different tasks (range of 0.88-88 μT). These results suggest no unusual risk of cancer for electric railway workers and partially contradict preliminary results presented by this group previously (Tynes and Andersen, 1990).

A number of epidemiologic studies have included railroad and subway workers within an "EMF-exposed" occupational category without explicitly calculating risk estimates for rail workers as a distinct occupational sub-category. Wilkins and Hundley (1990) conducted an epidemiologic study of the risk of neuroblastoma in the children of men with presumed occupational exposure to electromagnetic fields. Their primary occupational category replicated the grouping in an earlier study by Spitz and Johnson (1985) and included electric power and telephone linemen, power station operators, electrical engineers, welders, and electronic repairmen. In this occupational grouping, they found an odds ratio (OR), defined as the ratio of the risk of developing the disease in the exposed group to that for the unexposed general population, of 1.6 (0.3-9.1 95% confidence interval (CI)). However, a category which also included railroad and telecommunication workers, electricians, and repairmen had an OR of 1.9 (0.4-9.7 CI).

An epidemiologic study using data from death certificates of adult white male Maryland residents who died of brain tumors during the period 1969 through 1982 was conducted by Lin *et al.* (1985). Men in an occupational category characterized as "definite exposure to EMF" (electric and telephone servicemen, linemen, foremen and engineers; railroad and telecommunication engineers; electricians, electric and electronic engineers in industry) were found to experience a significantly higher proportion of primary brain tumors (gliomas and astrocytomas) than controls (27 cases, 14 controls; OR = 2.15). In one study of occupational associations with male breast cancer, Tynes and Andersen (1990) reported an elevated standardized incidence ratio (SIR) for all electrical occupations (12 cases observed, 5.81 expected; SIR of 207, 107-361 CI) with the highest SIR for the subgroup of electrical transport workers (railway engine drivers, tram drivers, and railway track walkers; SIR of 396 (108-1014 CI, 4 cases). However, as noted above, more recent results from a study of Norwegian transport workers failed to support the latter finding (Tynes *et al.* 1993). Comparing these studies to other occupational studies, it is apparent that current electric rail workers are at no obviously greater or lesser risk than other electrical workers.

A few residential epidemiologic studies have included presumed exposure to electric rail substations or systems in defining the "EMF-exposed" category. Tomenius conducted a survey of sources of 50 Hz EMF near the homes of pediatric tumor patients (716 cases) in Stockholm County, Sweden (Tomenius 1986). Magnetic field measurements were recorded and correlated with visible electrical constructions occurring within 150 m (490 feet) of the dwellings; electrical constructions included high-voltage wires (6-200 kV), substations, transformers, electric railroads, and subways. Of the dwellings visited, 196 (9.3%) were located within 150 m of an electrical construction. Magnetic fields of 3 mG or more were recorded at 48 dwellings; of these, the number of dwellings of tumor cases was significantly higher than expected. Conversely, tumor case dwellings showed a significant excess of total visible electrical constructions, but, as a group, only 200 kV wires were associated with a significantly higher number of case dwellings than expected (2-fold increase in tumor rate for birth dwellings and 2.3-fold for diagnosis dwellings). Cases were divided into five diagnosis groups; four of these five showed an association between tumor dwellings and magnetic fields greater than or equal to 3 mG, although only the nervous system tumor group had a significant association.

A dramatic claim of an association between residential proximity to electrical railroads and risk of sudden infant death was made by Eckert (1976). He conducted on-site investigations of 200 cases of crib death in Philadelphia, PA, and 294 cases in Hamburg, West Germany. Eckert claimed a high incidence of crib death in buildings near electric railroad and subway lines, high-voltage power transmission lines, water mains magnetized by power supply lines, transmitting antennae, airports, and churches with lightning rods in Philadelphia, and that the incidence of crib death was highest in temporary accommodations built near railroad and subway lines, and high-voltage transmission lines, especially when combined with high groundwater level, in Hamburg. The risk of crib death was higher in cellars and first-floor apartments than in higher floors. Eckert concluded that the findings indicated a possible causal relationship between crib death and abnormal electromagnetic fields and stray currents in the ground, hypothesizing that magnetic and/or electric fields provoke irreversible changes in the regulatory system of infants who are sensitive to such fields or have been sensitized by the fields. To our knowledge this report has not been replicated or supported with quantitative data, and was severely criticized at the time of publication for methodological weaknesses (Schaefer and Silny 1977).

In summary, there are no epidemiologic studies of which we are aware which clearly associate human health risks with specific occupational, or residential exposure to electrical railroad systems. Studies which explicitly considered exposures from railroad systems are few and their sample sizes, especially with reference to individuals exposed to electrical railroads, clearly inadequate. These few studies have also been conducted in Europe, and it is not known if the 50 Hz European EMF environment, and different power distribution arrangements, might produce biological effects which differ from those produced by the 60 Hz U.S. system. Epidemiologic studies involving presumed ELF EMF exposure, derived primarily from power delivery systems, are discussed in Section IV of this report. Risk estimates associated with exposure to these more general sources of power frequency EMF suggest at most a small increased risk of cancer and other diseases. If the increased risks involved are of a similar magnitude, it may be impossible to conduct a meaningful epidemiologic study with the relatively small populations exposed to electrical railroad EMFs because the sample size will never be large enough for statistical significance.

4. DOSIMETRY: CHARACTERIZATION OF EMF EXPOSURE OF RAILROAD WORKERS, UTILITY WORKERS, AND THE GENERAL PUBLIC

As epidemiologic studies generally report risk estimates for occupational categories involving presumed exposure to EMF, there is need to resolve which specific factors in an occupational setting might contribute to increased risks to health. Job category is recognized as an extremely indirect surrogate measure of exposure, so there has been an effort to better characterize typical occupational exposures. A particular problem is the occurrence of confounding factors (confounders) which also may be responsible for the observed health effects, but which are distributed unequally among the control and study populations. Examples of such confounders are coffee drinking, smoking, diet, air pollution, radon, and occupational or environmental chemicals. Several studies are currently in progress in which occupational exposures to EMF are being documented by careful measurements, while a range of possible confounding exposures, such as chemicals and stress factors, also are being monitored.

4.1 GENERAL OCCUPATIONAL ENVIRONMENTS

Bengt Knave and coworkers at the National Institute of Occupational Health in Sweden, are making detailed exposure assessments of both physical and chemical work environment factors for many occupations with presumed EMF exposure, including: electronic and electrical power engineers and technicians; electronic equipment fitters and repairmen; railway and subway engine drivers and assistants; railway conductors; and substation workers and linemen in the electrical power industry (Knave *et al.* 1987). As part of the research program on possible biological effects of 50 Hz electric fields, the ENEL (Italian Electricity Board) has developed mobile instruments for electric and magnetic field measurements appropriate for use in the environment of electrical installations (Armanini *et al.* 1989).

Similar ELF EMF measurements from 0-1000 Hz were conducted by Bowman and Kardous (1991) at 28 work locations in electric utilities; electronics facilities; machine shops; and offices in New Zealand, Los Angeles, and Seattle. Several personal recording dosimeters have been developed and used in programs to monitor occupational EMF exposure patterns, primarily of electrical utility personnel, or the ambient EMF environment in residential settings (Niple *et al.* 1989; Lindh and Andersson 1988). Bracken *et al.* (1990) reported the results of the EPRI EMDEX Project, a technology transfer program to involve individual utilities in the process of collecting 60 Hz electric and magnetic field measurement data associated with a variety of work activities. Over the time interval October 1988 to September 1989, field exposure data were collected for utility employees at 59 sites in the U.S. and three other countries, representing approximately 47,000 h of magnetic field and 20,000 h of electric field exposure records taken at 10-second (s) intervals, of which 70% were from work environments. Exposures and time spent in different classes of environments were analyzed by primary work environment, by occupied environment, and by job classification. Generally, the measured fields and exposures in the generation, transmission, distribution and substation environments were higher than in other occupational environments. Ontario Hydro is conducting a similar dosimetry/health effects study (Walsh 1988).

In a report based on EMDEX meter measurements, Kaune, *et al.* (1989) gave summary exposure statistics for workers in various job-title categories. Parametric tests indicated that there were substantial differences in workday exposure among the six job categories, with workers in power plants on standby status having the lowest (geometric means of the median and 90th percentile being 1.0 mG and 3.1 mG, respectively) and transmission linemen the highest (geometric means of median and 90th percentile, 5.4 mG and 61.7 mG, respectively) exposure. Bowman *et al.* (1988) have taken the approach of measuring ELF (below 100 Hz) electric and magnetic field intensities at 114 work sites of classes of workers identified in epidemiologic studies as being at higher risk for leukemia, presumably due to EMF exposure. In all work environments, the geometric means of the magnetic field exposures were higher than mean residential exposures, with the exception of radio dispatchers and a few specific environments of electronics engineers, technicians, and assemblers. Measurements ranged from 0.3 mG for radio operators to 103.1 mG for electricians - a 343-fold difference. The geometric means within the electronic assembler category varied 810-fold among the different environments. Forklift operators, an occupational group not generally identified as an "electrical" occupation in most epidemiologic studies, were exposed to the highest magnetic fields, ranging from 54 to 109 mG while in steady motion, with surges up to 1.25 G when accelerating.

These field intensities may not appear large in the context of Earth's geomagnetic field of 300-800 mG, but the latter, being a static or DC field, may not be biologically comparable to the time-varying fields generated by the equipment. Some laboratory experiments suggest that bioeffects depend strongly on the specific ELF frequency and intensity of EMF exposure (see section VII) or the rapidity with which the field is reversed or turned off and on (Wilson and Anderson 1989, Reiter *et al.* 1990; Lerchl *et al.* 1991). The interaction of DC and time-varying fields also forms the basis for certain theoretical mechanisms to explain the effects of weak EMFs, such as the ion cyclotron resonance model (Liboff *et al.* 1989).

4.2 RESIDENTIAL ENVIRONMENT

Estimates of residential exposure have been attempted, and generally they also indicate substantial variation in individual exposures within groups of individuals identified as "exposed." Power-frequency (50 Hz) magnetic field assessments of the residential environment, using small light-weight personal exposure monitors developed by the Institut de Recherche d'Hydro-Quebec (IREQ), were being conducted by National Grid Research and Development Centre, Central Electricity Generating Board, UK, and were reported by Renew *et al.* (1990). Typical daily variations in field intensity were significant: mean exposure for mobile "at home" readings (1.35 mG) exceeded mean static readings by 0.81 mG, indicating a significant contribution from appliances and localized fields; the range of variation in average magnetic fields in different homes was considerable (0.06-1.21 mG), and was significantly greater when a high voltage line was located within 100 m (0.20-4.09 mG). The range of average "at work" exposures was even larger (0.56-88.41 mG).

4.3 MAGLEV AND OTHER RAIL TRANSPORT SYSTEMS

Maglev and other electrified rail transport systems have not, as yet, been studied extensively with respect to the frequencies, intensities, and time variation of their EMF emissions. Since 1990, Electric Research and Management, Inc. (ERM), has been making measurements of electric rail systems with the support of the U.S. Department of Transportation, and have characterized the frequency/intensity electric and magnetic field environments of one maglev and a number of conventional electric rail systems. Results of these measurements are discussed later in this section. In general, electric rail systems are characterized primarily by EMF in the extremely low frequency (ELF) range (0-300 Hz; there are definitions of ELF as 0-3 kHz or even 0-30 kHz in some references), with more prolonged and higher intensity exposure at power frequencies and below. EMF emissions extending into the radiofrequency range are produced by railroad communications and control technology, and as harmonics of lower frequencies, but in terms of intensity and duration of exposure these EMFs tend to be secondary, as are the VDT emissions in railroad control facilities.

Work aimed at characterizing the EMF emissions from a variety of transportation systems is currently in progress, but will not produce detailed information immediately applicable to exposure risk assessment. This is not only because the more sophisticated measurements that are needed may require technical developments in instrumentation, but more importantly, because the biologically-relevant EMF parameters, from among such characteristics as frequency, rise time (rate of change of intensity), fluctuations (number of on/off or intensity change per unit time), steady-state intensity, static and time-varying field interactions, are not currently known. This is also true of other sources of EMF emissions, although the transients of power transmission systems have been characterized to some extent for reasons of engineering efficiency (rather than in anticipation of biological effects). Field characterization in terms of health impact will necessarily be a recursive and evolutionary process: measurement studies will be completed, but might have to be repeated and extended as more information becomes available to suggest which field characteristics are biologically relevant.

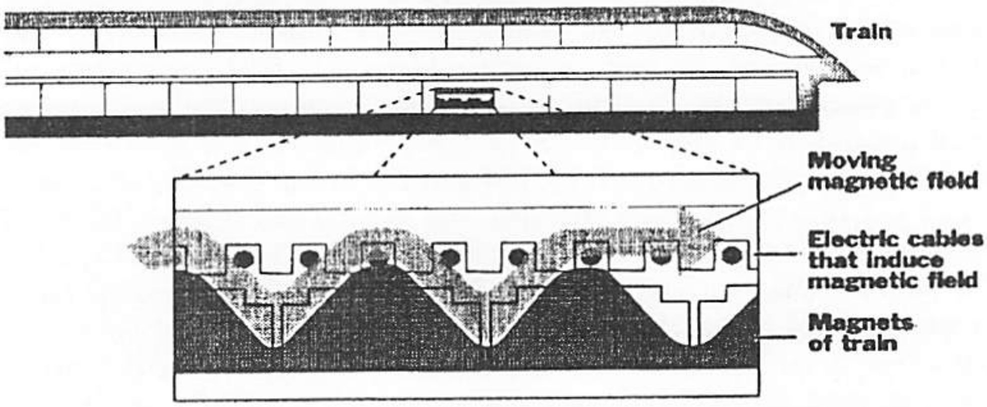
There are currently two major designs for magnetically levitated ground transportation (maglev) systems. Although both rely on magnetic fields for suspension and propulsion, the Japanese (EDS) and German (EMS) maglev designs employ different technologies for levitation, as is illustrated in Figure 1, derived from an article by Browne in *The New York Times* (Browne 1992). In the German design, an AC magnetic field generated in the active guideway below the vehicle floor, supports the train by pulling the car up towards magnets on the guideway's lower surface; while in the Japanese design, DC fields produced by superconducting magnets at points along the sides and underneath of the train are used to center it in a semi-circular guideway. These two distinct arrangements for supporting the train might be expected to result in differing EMF exposure patterns for operating personnel and passengers. The positioning of the magnets also could result in higher magnetic field exposure to persons in and around the train; i.e., exposure can be minimized by relocating the magnets to the connecting portion between cars. The field from a switched phase synchronous linear motor is used for acceleration and primary braking of the train, by varying the excitation voltage and frequency. Secondary breaking is achieved by using the longitudinal guidance magnets to induce eddy currents in the track guide rails, thereby producing an electronic drag.

The magnetic field exposure and degree of field cancellation experienced by passengers and operators would reflect the arrangement of these fields relative to the passenger compartment and cabin. Partial shielding and reshaping due to the presence of ferromagnetic objects, such as steel used in construction of the train, supporting guideway, and superstructure, would also alter the field distribution. Superimposed on these fields would be electric and magnetic fields associated with power delivery to the system; higher frequency fields used in communication and control of the system; and interacting fields from parallel tracks or power delivery systems using the same corridor. Persons using the rail system would be exposed, therefore, to a complex net field with frequency and intensity characteristics which would be a function of train speed; proximity of the train to other trains and electrical structures at any particular time; and whatever magnetic shielding might be developed. As indicated in *The New York Times* article, present prototype test vehicles may be operating with a smaller distance between the train and the track than would be considered safe in actual passenger use, and increasing the distance to the ground would require substantial increases in magnetic field strength.

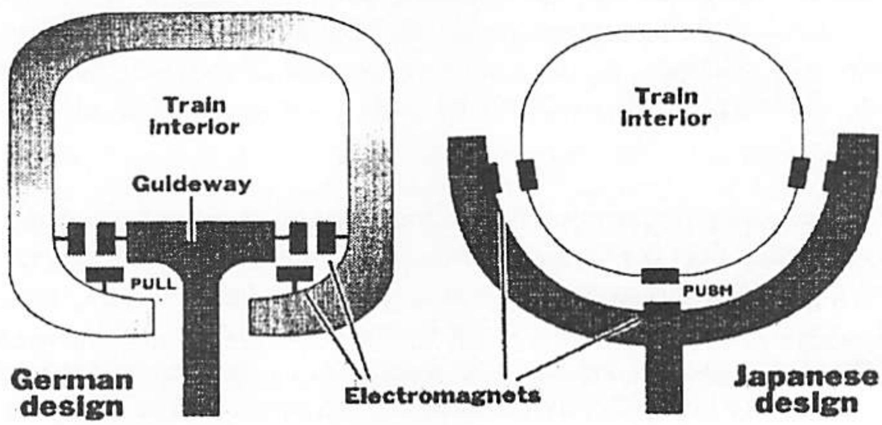
Only one full-scale study has been made of an existing prototype maglev transportation system, the German TR07 Maglev System at the Emsland Transrapid Test Facility (Cummings and Robertson 1990; Dietrich *et al.* 1991; Dietrich and Feero 1992). This study made use of a computer-based digital magnetic field measurement system (*MultiWave*™) to capture the intensity, frequency and temporal distributions of fields present at ten sensor locations. AC magnetic field emissions occur primarily in the 0-300 Hz range, with more transient and intense emissions in the 2-47.5 Hz bandwidth than is characteristic of power-frequency fields. Indeed, fields in the 47.5-62.5 Hz bandwidth were of lower intensity than those below or above (65-300 Hz) this range; the latter reflect power-frequency harmonics and the frequencies used for propulsion. The AC magnetic flux density decreases with height above the TR07 floor from the 100-300 mG (usually less than 100 mG) range at floor level to <10 mG at standing head level. Frequency components are dominated by the train excitation frequency which is proportional to vehicle speed, its harmonics and subharmonics. Both the magnitude and frequency of the magnetic flux density vary with operating mode. The DC magnetic field falls from within about 400 mG of the ambient geomagnetic field at floor level to within about 100 mG of that value at head height. It should be noted that FRA Senate testimony regarding the Japanese maglev cited DC magnetic fields possibly as high as 600 G, or in the range 20-400 times greater than the geomagnetic field. The Japanese maglev prototype has since been destroyed in an accident, before any comprehensive dosimetry had been performed. However, it was estimated in a presentation at the recent *First World Congress for Electricity and Magnetism in Biology and Medicine*, that maximum DC fields would be 10-200 G, and AC fields in the car no more than 0.1-1.0 G; the latter chiefly when passing another train, since engineering requirements determine that the attractive and repulsive forces of the linear synchronous motors have to be static on the train and are most effective when there are no ripples. In general, it has been claimed that both AC and DC field intensities will be several times lower than for conventional trains (Nakagawa 1992), and this statement is supported to some extent by measurements made by ERM of U.S. and French high-speed rail trains.

The EMF environment of other electric railroad systems had not been studied intensively until recently, but preliminary data are now becoming available which suggest that both occupational and passenger exposures may be higher than most power-frequency EMFs commonly encountered by the general public, with the exception of certain appliances which are used for

Magnetic Propulsion for High Speed



In this side view of a magnetically levitated train, each of the fixed electromagnets along the guideway creates a moving magnetic wave by switching polarity whenever one of the train's propulsion magnets passes over it, alternately pulling and pushing the vehicle.



In the German version of magnetic levitation, electromagnets slung from each car pull the car up toward magnets on the guideway's lower surface; another set of magnets along the sides keeps the train centered, with no friction. In a Japanese version, magnets in the guideway repel magnets on the train so that it floats above the track.

Source: Transrapid

Source: *The New York Times*, March 3, 1992

FIGURE 4-1. BASIC DESIGN OF MAGLEV PROTOTYPE TRAINS

brief durations. The EMFs generated by conventional trains may, indeed, exceed in intensity those associated with the prototype TR07 maglev, although they lack some of the complex harmonics and the speed-dependent characteristics of the latter.

Detailed magnetic field measurements were made by Electric Research and Management, Inc., on the Amtrak Northeast Corridor and New Jersey Transit trains in the U.S. (Dietrich and Feero 1993; Dietrich *et al.* 1993a). EMDEX-II personal exposure meters and the *MultiWave*™ computer-based recording system and real-time digital audio tape recordings were used for complete study of the frequency, intensity and spatial and temporal variation in magnetic field characteristics in and around the train systems. Major AC field components reflected the frequency of the power supplies (25 or 60 Hz) and their harmonics and subharmonics. For 25 Hz sections of the AMTRAK Northeast Corridor, maximum and average fields, respectively, in the coaches (in mG) were approximately: 624 and 132 mG at 5-45 Hz; 26.9 and 5.9 mG at 50-60 Hz; 72.8 and 16.2 mG at 65-300 Hz; and 11.4 and 2.7 mG at 305-2560 Hz. For 60 Hz sections, maximum and average fields were: 9.0 and 1.4 mG at 5-45 Hz; 304 and 52 mG at 50-60 Hz; 27.3 and 5.7 mG at 65-300 Hz; and 7.5 and 1.4 mG at 305-2560 Hz. For non-electrified diesel-powered trains, the corresponding values were: 3.9 and 1.4 mG at 5-45 Hz; 12.5 and 6.0 mG at 50-60 Hz; 2.4 and 0.9 mG at 65-300 Hz; and 0.8 and 0.3 mG at 305-2560 Hz. The 60 Hz band in the 25 Hz-powered trains and the EMFs in diesel trains were attributable mainly to the "hotel power" cables, on-coach equipment, and external non-railroad power sources. Electric (60 Hz) trains on the North Jersey Coast Line from Matawan to Long Branch showed lower maximum and average fields at 50-60 Hz (59.8 and 18.2 mG) and at 65-300 Hz (9.4 and 2.5 mG) than the corresponding AMTRAK trains. This difference did not appear to be related to differing ferromagnetic shielding by the aluminum versus stainless steel (AMTRAK) body, as evidenced by the similar penetration of the static geomagnetic field, but the role of any shielding effects produced by eddy currents or other factors remains to be determined.

In general, average power-frequency fields in the coaches were higher for the 25 Hz system (approximately 130 mG) than the 60 Hz systems (19-52 mG), with the strongest fields, at floor level, 3-5 times higher than the average. Average magnetic fields in the locomotive cabs were 46 mG (25 Hz power) and 27-28 mG (60 Hz system). Unlike the TR07 maglev system, the frequency spectrum of these rail systems was dominated by the power frequency band and its odd harmonics, with very little intensity below power frequencies. The ERM report generalized the AC magnetic fields produced by these systems as "very similar to those near many electrical appliances" (Dietrich *et al.* 1993a).

ERM has also completed similar measurements on the French high-speed rail system a Grande Vitesse-Atlantique (TGV-A) which operates with 25 kV, 50 Hz AC power or, in different sections of track, 1500 V DC power (Dietrich *et al.* 1993b). DC magnetic fields in the DC-powered section averaged 913 mG (maximum 3.066 G) in the coaches. AC fields in the 50 Hz sections averaged 31 mG (maximum 165 mG). In the coach, the highest magnetic fields were at the floor and ceiling, due to the proximity of the catenary and 25 kV power line above the car. Measurements made on DC-powered trains operating on the Massachusetts Bay Transportation Authority (MBTA) system in the Boston area indicated a similar level of exposure (Dietrich *et al.* 1993c). The predominant magnetic fields were static, associated with the DC propulsion system of the trains, with some low frequency components resulting from fluctuations in the DC field level and rectifier ripple in the DC power supplies. Onboard subway cars, the average static magnetic field intensity was 507 mG, with a maximum of 1446 mG at seat level. On the Mattapan High Speed Trolley, the average static magnetic field was 1501 mG (maximum 3.074 G) at floor level and averaged 517 mG (774 mG maximum) at seat height. In characterizing these fields, the authors of the report described them as similar to magnetic fields near appliances with varying load or intermittent use. Therefore, electric rail transportation systems expose workers and passengers to magnetic fields with much greater variability than fields associated with electric power transmission lines.

Chadwick and Lowes (1992) have presented data on the various systems that are currently in use in the United Kingdom. A full discussion still awaits the official clearance and publication of the report. On the 600 V DC London Underground, for example, DC fields are 20 G at floor level, falling to 2 G at seat level. This system is being changed to AC, with one experimental train showing floor-level DC fields of 440 G, and substantial 100 Hz components due to rectifiers under the floor. For the 25 kV AC overhead system with inductors under the floor, a 1-inch steel plate is necessary to bring DC and 100 Hz fields down to 150 G at floor level. On standard British Railways intercity trains, EMDEX measurements indicate maximal DC fields of 350 and 25 G at floor and seat levels, respectively, with the passengers exposed to an average field of 300 mG. Interestingly, because of the location of the inductors and rectifiers beneath the floors of the passenger compartments, operators experience lower exposures than passengers.

With the present scientific uncertainty regarding which features of EMFs are potentially biologically active, decisions regarding the safety of fields produced by maglev systems are limited as much by lack of knowledge as to what field characteristics are harmful as by limited data on EMF emissions themselves. In general, DC fields in themselves seem to have little or no biological effect at levels below 1 T (10 kG; discussed in section V). Weak time-varying magnetic fields (on the order of a few mG or lower) have been implicated in some bioeffects and, based on epidemiologic studies, human health effects (discussed in section IV). It will be important to further characterize the EMF environments around existing and proposed rail transport systems, so as to compare them with other common EMF environments produced by power distribution systems, appliances, and industrial machinery. Such an approach will be helpful, both from the legal standpoint of being able to characterize the EMF environment as common or atypical, and for facilitating quick action to mitigate exposure, if new biological data show clear implications for human health.

In summary, detailed measurements of spatial/temporal variation in magnetic field frequency and intensity for the electromagnetic environment produced by maglev trains, and indeed, by high speed electric rail transport systems in general, are only now beginning to become available. These have become of interest as a result of claimed adverse health effects of power frequency EMF. Electrified transportation systems produce magnetic field exposures which are generally similar in intensity to exposures from many electrical appliances, but the frequency spectrum and variation with time is different. It will not be possible to obtain a detailed picture of these exposures until complete prototype maglev systems are constructed; thus, allowing measurements to be made, for example, of two trains passing each other on a single right-of-way.

4.4 SHIELDING

Through a period of growing concern about potential negative health effects of ELF magnetic fields, a limited effort has been made to develop new technical approaches to reducing magnetic fields from various sources. The intent is to have magnetic field shielding technology available in case accumulated evidence indicates it is necessary from a public health standpoint. Also, with an interest in "prudent avoidance," or in an attempt to avoid future liability claims, there is some market trend among businesses to shield some sources of magnetic fields (especially video display terminals) in equipment. A limited number of products are also available which are designed to reduce ELF magnetic field exposures. Since magnetic shielding, or partial shielding, will probably be incorporated into final designs for electromagnetic high speed rail systems, a brief consideration of shielding technology is necessary for meaningful discussion of the projected electromagnetic environment of maglev trains. The concept of "shielding" to alternate magnetic fields implies that the "dose" is magnetic field strength, which is, as yet, an unproven assumption.

Magnetic field shielding is feasible, but developments are at a very preliminary stage, and it is not yet possible to predict how complete and cost-effective such shielding would be. If it were possible to define the specific EMF characteristics that are biologically harmful, or potentially so, with respect to such features as frequency, intensity and time variation (see discussion in the following section), it would be relatively easy to measure the relevant field characteristic of the railway systems, and arrive at reasonable field mitigation approaches. Even in the absence of such specific knowledge, however, some field management and minimization work has already been undertaken in the area.

Dr. Gordon Danby, of the Brookhaven National Laboratory, and one of the patent holders for the maglev design, was quoted in the March 3, 1992, *New York Times* article as expressing confidence that DC magnetic fields in the passenger compartment of superconducting maglev trains can be reduced by shielding to levels below those of the geomagnetic field. While there has been some effort to develop new shielding technology in the past few years, it may not be a simple matter to reduce magnetic field intensities to these low levels if there are possible human health concerns. Johnson *et al.* (1991) have described the usual approaches taken to lower the intensity of magnetic fields produced by power delivery systems, while Zhang *et al.* (1992) have discussed the levels of investment that are needed. Such measures, including conventional passive shielding, active and passive cancellation, and twisted pair and bifiliar cabling, have been examined and evaluated, and the potential order-of-magnitude reductions have been estimated. In general, DC shielding is less difficult and expensive than shielding (usually cancelling) time-varying AC magnetic fields, especially those that change with the speed of the train. It is the time-varying fields which have been implicated in producing health effects.

In general, the most cost-effective approach to reducing AC magnetic fields is to configure power distribution so that currents are balanced and the phases cancel; however, this is not always possible in view of differing loads and alternate ground paths. Technology is evolving that might produce very effective cancellation of specific fields, but the energy and weight costs may make the technology impractical for application to rail transport. For example, Takahata *et al.* (1989) reported preliminary studies on magnetic shields with superconducting windings made of Nb/Ti multifilamentary composite wires impregnated with Wood's metal. Static magnetic fields of up to 20 kG could be reduced to less than 10 G at the center of the shield, and it was possible to shield both parallel and transverse DC magnetic fields. Passive magnetic field shielding has been developed to solve compatibility (interference) problems over a broad frequency range, but the ferromagnetic alloys needed for effective shielding may not be appropriate for use in transportation systems (see Cresswell and Gowers 1989). For example, pig iron plates are a relatively inexpensive material for reducing penetration of magnetic fields. However, they are heavy, and as the British data showed, a 1 inch steel plate is only able to reduce floor level fields to 150 G, about 250 times the geomagnetic field, in conventional trains with the 25 kV AC overhead system (Chadwick and Lowes 1992). Any further reduction in fields by increasing the thickness of the plates would result in unacceptable increments in coach weights. While mu metal shielding is relatively light, which would minimize the weight problem, it is an extremely expensive alloy which is hard to fabricate and maintain. The approach of canceling out magnetic fields at specific frequencies, which has been used effectively in reducing ELF magnetic field emissions from video display terminals (Hojevik *et al.* 1991), may not be practical for the broad and speed-dependent frequency range, and time-varying nature of the EMFs produced by maglev trains. Finally, a better definition and understanding of the potentially harmful magnetic field characteristics is needed in order to adopt preventive, design-related changes, which are usually more cost effective than mitigation measures.

5. EPIDEMIOLOGIC STUDIES OF WORKERS AND THE GENERAL PUBLIC EXPOSED TO POWER FREQUENCY (50 AND 60 HZ) ELECTRIC AND MAGNETIC FIELDS

5.1 CANCER RISK

Concern about possible adverse health effects from EMF produced by maglev and other electric rail transport systems is based, in large measure, upon the results of a series of epidemiologic studies. These studies suggest that there is an increased risk of various forms of cancer associated with either residential proximity to power distribution systems, or employment in occupations with presumed higher than average EMF exposure. Considered together, these studies indicate a small but consistent increase in risk associated with exposure to the magnetic field component (rather than the electric field component) of power-frequency EMF. Since experimental studies have consistently failed to demonstrate any cytogenetic activity of such fields, a co-promoter rather than a causal role is generally assumed. This evidence is indirect, since the most appropriate exposure metric has not been defined; actual magnetic fields were generally not measured or well characterized in these studies; and for most studies surrogate metrics, such as wire codes, were used. The major national and international residential and occupational studies and their results are summarized in Tables 5-1 and 5-2.

TABLE 5-1. SUMMARY OF EPIDEMIOLOGIC STUDIES OF PRESUMED RESIDENTIAL EMF EXPOSURE AND CANCER INCIDENCE

Investigator and Date	Location of Study	Population Studied	Exposure Estimate	Type of Study	Number of Cases or Subjects	Risk Examined and Odds Ratio or Risk Ratio (95% Confidence Intervals)
Wertheimer and Leeper 1979*	Denver, Colorado	Children living near HCC	Wiring configuration	CC	344	Cancers (all) 3.2 Leukemia 3.0 CNS tumors 2.4
Fulton *et al.* 1980	Rhode Island	Children living near HCC	Wiring configuration	CC	119	Leukemia no increased risk
Wertheimer and Leeper 1982	Denver, Colorado	Adults living near HCC	Wiring configuration - some representative field monitoring	CC	1,179	Cancers (all) 3.2 CNS, breast, & uterus tumors, & lymphoma - largest increase
Tomenius 1986	Stockholm, Sweden	Children living near HV lines	Proximity to HV & monitoring outside house	CC	716	Cancers (all) 2.1 CNS tumors 3.7
McDowall 1986	East Anglia, UK	Persons living near HV lines & substations	Proximity to lines & substations	CC	7,631 (814 deaths)	Cancers (all) 1.04 (.88-1.23) Lung cancer 2.15 (1.18-3.61)
Coleman and Bell 1987	London, UK	Persons living near HV lines & substations	Proximity to lines & stations	CC	771	Leukemia 1.45 For children 1.6
Savitz *et al.* 1988	Denver, Colorado	Children living near HV lines	Proximity to HV, in-house measurements, wiring configuration (wiring best index)	CC	356	Cancer (all) 1.4 (0.6-2.9) Leukemia 1.9 Lymphomas 2.2 Soft tissue sarcomas 3.3
Severson *et al.* 1988	Washington State	Persons living near HCC	Wiring configuration over 15 yr, point in time field measures in & out of house	CC	114	Acute nonlymphocytic leukemia no increased risk
Preston-Martin *et al.* 1988	Los Angeles, California	Adults with leukemia	Electric blanket use	CC	116 AML 108 CML	Acute and chronic myelogenous leukemia no increased risk
Coleman *et al.* 1989	London area & South East, UK	Adults with leukemia	Proximity to electric supply (lines & substations)	CC	771	No significant risk increase, but suggested risk trends: <100 m from line 1.45 (0.54-3.88)
Myers *et al.* 1990	Yorkshire, UK	Children living near HV lines	Proximity to HV and field monitoring, mean 0.15 mG (0.01-4)	CC	374	Cancers (all) and leukemia (all) no increased risk (power to detect OR of 2.5)
Youngson *et al.* 1991	North West & Yorkshire, UK	Adults with leukemia & lymphoma	Proximity to power lines, spot measurements	CC	3146	No significant risk increase, but suggested risk/exposure trends: <100 m from line 1.26 (0.99-1.60)
London *et al.* 1991	Los Angeles, California	Children with leukemia	Wiring configuration, 24-hr measurements, self-reported appliance use	CC	232	Leukemia (VHCC) 2.15 (1.08-4.28) Leukemia (0.068-0.124 μT) 1.37(0.65-2.91) Leukemia (>0.124 μT) 1.22 (0.52-2.82) Leukemia (b&w TV use) 1.49 (1.01-2.23)

TABLE 5-1. SUMMARY OF EPIDEMIOLOGIC STUDIES OF PRESUMED RESIDENTIAL EMF EXPOSURE AND CANCER INCIDENCE (continued)

Investigator and Date	Location of Study	Population Studied	Exposure Estimate	Type of Study	Number of Cases or Subjects	Risk Examined and Odds Ratio or Risk Ratio (95% Confidence Intervals)
Feychting *et al.* 1992	Sweden	Children & adults living near HV lines	Calculated historical magnetic field levels, spot measurements, 24-hr personal measurements, distance from HV line	CC	141 children 546 adults (1637 controls)	Childhood Leukemia (<17 yr old) >0.2 μT historical 2.7 (1.0-6.3) >0.3 μT historical 3.8 (1.4-9.3) 0-50 meters from line 2.9 (1.0-7.3) >0.2 μT spot measurement 0.6 (0.2-1.8) Adult Leukemia (>0.2 μT historical) AML 1.7 (0.8-3.5) CML 1.7 (0.7-3.8)
Lin and Li 1992	Taipei, Taiwan	Children with leukemia	Proximity of school to HV line	SMR	67	Leukemia (all ages) 1.49 (1.17-1.89) Leukemia (0-4 yr old) 1.71 (1.24-2.35)
Olsen *et al.* 1992	Denmark	Children with leukemia, lymphoma, or brain tumor	Proximity of residence to HV line and line load	CC	1707 cases (4788 controls)	Lymphoma (>0.1 μT) 5.0 (1.2-21) All Cancers (>0.4 μT) 5.6 (1.6-19) All Others -- not significant

*Ratio calculated by Aldrich and Easterly 1987

Abbreviations:

CC	Case Control
HCC	High Current Configuration
RFU	Retrospective Follow-up
AML	Acute Myelogenous Leukemia
SMR	Standardized Mortality Ratio
CNS	Central Nervous System
HV	High Voltage
VHCC	Very High Current Configuration
CML	Chronic Myelogenous Leukemia

TABLE 5-2. SUMMARY OF EPIDEMIOLOGIC STUDIES OF PRESUMED OCCUPATIONAL EMF EXPOSURE AND CANCER INCIDENCE

Investigator and Date	Site	Workers and Exposure Type	Type of Study	Number of Cases or Subjects	Diagnostic or Occupational Risk Examined and Odds Ratio or Risk Ratio (95% Confidence Intervals)
Wiklund and Eklund 1981	Gothenburg, Sweden	Telephone operations	PMR	12 deaths	Leukemia no increased risk
Milham 1982	Washington State	Electrical workers: elevated risk in 10/11 occupations	PMR	196 deaths (438,000 pop.)	Leukemia (all) 1.4 Acute leukemia 1.6
Wright, Peters, and Mack 1982	Los Angeles, California	Electrical workers: greatest exposure & risk for linemen	PIR	35 with leukemia	Leukemia (all) 1.3 Acute leukemia 1.7 AML 2.1
Swerdlow 1983	England & Wales	All occupations	PIR	4,284	Eye melanoma elevated for electrical & electronics workers in 3/6 time periods examined
McDowall 1983	England & Wales	Electrical workers: greatest risk electrical engineering & telecommunications	PMR/ CC	98 deaths	AML 2.3 (1.4-3.7) AML - for telecommunication engineers 4.0 (0.8-17.0)
Coleman, Bell, and Skeet 1983	S.E. England	Electrical workers: greatest risk electrical fitters, telegraph operators	PIR	113 with leukemia	Leukemia (all) 1.2 ALL 1.5 AML 1.2
Vagero and Olin 1983	Sweden	Electronics workers: greatest risk in radio & TV industry	RFU	2,864 with cancer (73,102 workers)	Cancer (all) 1.1 (1.0-1.2) Mesopharynx 2.2 (1.1-4.7) Hypopharynx 1.7 (0.9-3.3) Lung (men) 1.4 (1.2-1.5)
Pearce *et al.* 1985*	New Zealand	Electrical workers: greatest risk radio/TV repair, then electricians	PIR/ CC	546 with leukemia	Leukemia (all) 1.7 (1.0-3.0)
Milham 1985*a*	Washington State & California	Amateur radio operators	PMR	24 with leukemia (1,691 deaths)	Leukemia (all) 1.9 AML 2.9 CML 2.7
Lin *et al.* 1985	Maryland	Workers in all occupations, estimated EMF exposure	CC	951 deaths from brain tumors	Definite exposure 1.5 (0.7-3.4) Probable exposure 1.3 (0.6-2.8) No exposure 1.0
Gilman, Ames, and McCawley 1985	USA	Underground miners	RFU	40 with leukemia (6,066 deaths)	Leukemia (all) 2.5 Chronic 8.2 CLL 6.3 Myelogenous 4.7
Spitz and Johnson 1985	Texas	Workers in all occupations with children having neuroblastoma	CC	157 deaths, neuroblastoma in children	Electrical workers 2.1 (1.1-4.4) Electronics workers 11.8 (1.4-98.6)
Olin, Vagero, and Ahlbom 1985	Sweden	Electrical engineers	RFU	108 deaths	Melanoma 3.2 (0.7-9.4)

TABLE 5-2. SUMMARY OF EPIDEMIOLOGIC STUDIES OF PRESUMED OCCUPATIONAL EMF EXPOSURE AND CANCER INCIDENCE (continued)

Investigator and Date	Site	Workers and Exposure Type	Type of Study	Number of Cases or Subjects	Diagnostic or Occupational Risk Examined and Odds Ratio or Risk Ratio (95% Confidence Intervals)
Vagero *et al.* 1985	Sweden	Telecommunication workers	RFU	139 with cancer	Melanoma 2.5 (1.1-4.9) Melanoma for soldering-workers 3.9 (1.4-8.5)
Milham 1985*b*	Washington State	Workers exposed to EMF in 9 occupations	PMR	317 deaths (12,714 total)	Lymphomas (all) 1.2 Leukemia (all) 1.4 Acute leukemia 1.6
Calle and Savitz 1985	Wisconsin	Workers in 10 occupations involving electricity	PMR	81 leukemia deaths	Leukemia (all) 1.0 Radio & telegraph operators 2.4
Tornqvist *et al.* 1986	Sweden	Workers in electric power industry	RFU	699 deaths (10,061 workers)	Cancer (all) 1.0 Urinary tract cancer Linemen 1.2 (0.8-1.8) Power station operators 1.3 (1.0-1.7)
Stern *et al.* 1986	New Hampshire	Nuclear shipyard workers: elevated risk only for electrical workers, welders	CC	53 leukemia deaths	Leukemia (all) 3.0 (1.3-7.0) Lymphatic leukemia (electrical) 6.0 (1.5-24.5) Myeloid leukemia (welders) 3.8 (1.3-11.5)
McLaughlin *et al.* 1987	Sweden	All job categories	PIR	4,429 brain tumors	SIR 0.9 No apparent relation to non-ionizing radiation in electrical workers
Lin 1987	Taiwan	Electric power company workers	PMR	733 deaths	Liver cancer, brain tumors, & leukemia/lymphoma - significantly elevated ($p < 0.01$)
Thomas *et al.* 1987	Northern New Jersey, Philadelphia, Louisiana Gulf Coast	Electrical & electronics workers - including microwave & radiofrequency	CC	435 brain tumor deaths	All jobs 1.6 (1-2.4) Repairers 4.6 Assemblers 5.6 Soldering 3.4 Electrical engineers 2.2 Technicians 4.1
Tornqvist *et al.* 1987	Sweden	Workers occupationally exposed to low frequency magnetic fields	RFU	325 leukemias	CLL 1.7 (1.1-2.5)
Coleman and Beral 1988	International	Meta-analysis of 11 studies of presumed EMF-exposed occupations & leukemia	CC/ PMR	(not specified)	All leukemias 1.18 (1.09-1.29) AML 1.46 (1.27-1.65)
De Guire *et al.* 1988	Montreal, Canada	Workers (9,590) in telecommunications company	SIR	10 melanomas	Melanomas 2.7 (1.33-5.02)
Lin 1988	Taiwan	Telephone & telegraph company workers	PMR	374 deaths (129 cancer deaths)	No general increase in cancer deaths Brain tumors 2.4 (0.78-5.59)
Linet *et al.* 1988	Sweden	All job categories	PIR	5,351 leukemia cases	Electrical line workers (SIR) CLL 1.9 (13 cases) ALL 1.4 (8 cases)

TABLE 5-2. SUMMARY OF EPIDEMIOLOGIC STUDIES OF PRESUMED OCCUPATIONAL EMF EXPOSURE AND CANCER INCIDENCE (continued)

Investigator and Date	Site	Workers and Exposure Type	Type of Study	Number of Cases or Subjects	Diagnostic or Occupational Risk Examined and Odds Ratio or Risk Ratio (95% Confidence Intervals)
Speers, Dobbins, and Miller 1988	East Texas	Workers exposed to EMF	CC	202 deaths	Brain tumors (gliomas) 3.94 (1.52-10.20)
Wilkins and Koutras 1988	Ohio	Workers with children having brain tumors	CC	491 cases	Father employed in: Electrical assembly/repair 2.7 (1.2-6.1) Machinery industry subgroup 3.6 (1.3-10.0)
Flodin *et al.* 1990	Sweden	Electrical workers	CC	86 AML	AML (electrical work) 2.1 (0.7-5.9) (early results for 59 AML cases had OR of 3.8 (1.5-9.5) (Flodin et al. 1986))
Garland *et al.* 1990	All states in USA	US Navy personnel with leukemia	SIR	123 cases (102 verified)	No general increase Electrician's mate subgroup, all leukemia (85% myeloid) 2.5 (1.0-5.1)
Tynes and Andersen 1990	Norway	Electrical workers: greatest risk with long-term employment	SIR	12 men with breast cancer	All electrical work 207 (107-361) All electrical work (>10 yr) 252 (93-549) Electrical transport work 396 (108-1014)
Loomis and Savitz 1990	16 states in USA	Electrical workers: greatest risk of brain cancer in men over age 65, electrical engineers & technicians, telephone workers, electric power work, & electrical work in manufacturing	PMR	2,173 brain cancer deaths; 3,400 leukemia deaths	Brain cancer: All electrical work 1.4 (1.1-1.7) Over age 65 yr 1.9 (1.3-2.7) Leukemia: Engineers, technicians 2.7 (2.1-3.4) Telephone work 1.6 (1.1-2.4) Electric power work 1.7 (1.0-2.7) Other industries 1.7 (1.1-2.5)
Balli-Antunes, Pfluger, and Minder 1990	Switzerland	Railroad workers dying of hematopoietic and lymphatic system malignancies 1969-1983	PMR	23	Versus metal construction and machine building workers 1.44 (0.91-2.17) Versus technical personnel 1.63 (1.03-2.44)
Wilkins and Hundley 1990	Ohio	Workers exposed to EMF with children having neuroblastoma	CC	101	All electrical workers 1.6 (0.3-9.1) Definite EMF exposure 1.9 (0.4-9.7)
Demers *et al.* 1991	USA	Male workers in all occupations diagnosed with breast cancer 1983-1987	CC	227	All EMF exposure 1.8 (1.0-3.7) Electric trades 6.0 (1.7-21) >30 yr exposure 3.1 (1.2-7.9) >30 yr exposure & exposure before age 30 3.3 (1.5-7.3)

TABLE 5-2. SUMMARY OF EPIDEMIOLOGIC STUDIES OF PRESUMED OCCUPATIONAL EMF EXPOSURE AND CANCER INCIDENCE (continued)

Investigator and Date	Site	Workers and Exposure Type	Type of Study	Number of Cases or Subjects	Diagnostic or Occupational Risk Examined and Odds Ratio or Risk Ratio (95% Confidence Intervals)
Gallagher *et al.* 1991	British Columbia	Male adults with brain & central nervous system cancer	PMR	320,423	All EMF exposure 121 (93-154) Electrical engineers 163 (52-380) Radio/TV work 165 (34-483) Projectionists 408 (84-1192) No increased risk for other electrical occupations; risk for high SES groups (civil engineers PMR = 239 (139-384))
Matanoski, Breysse, and Elliott 1991	New York State	Telephone workers in 5 jobs with EMF exposure	PIR	2 men with breast cancer (50,582 workers)	Central office technicians 6.5 (0.79-23.5) 4 additional cases outside study period : 2 among same group of technicians
Olsen *et al.* 1991	Denmark	Workers in all occupations with children having cancer	CC	1,747 children	No elevated risk for childhood cancer with parental employment in electrical occupations
Tornqvist *et al.* 1991	Sweden	Workers in 11 electrical occupations	PMR	133,687 workers	Electrical engineers & technicians Total leukemia 1.3 (1.0-1.7) CLL 1.7 (1.1-5.7) Telephone/telegraph workers Total leukemia 2.1 (1.1-3.6) Ore miners - AML 5.7 (2.1-12.4) Power linesmen - CLL 2.8 (1.1-5.7) Radio/TV repair - glioblastoma 3.4 (1.1-8.0)
Floderus *et al.* 1992	Mid-Sweden/ Gothenburg county	All male cases with leukemia or brain tumors 1983-87; EMF exposure in job held longest in decade before diagnosis	CC	250 leukemias, 261 brain tumors	CLL Mean EMF>0.41 μT 3.72 (1.79-7.74) Ever having EMF>0.28 μ T1.27 (0.9-1.81) Brain tumors Median EMF>0.2 μT 1.63 (1.04-2.56) Ever having EMF>0.28 μ T1.27 (0.9-1.78) AML, no increased risk
Guenel *et al.* 1992	Denmark	All actively employed Danes 20-64 yr of age in 1970	SIR	3,932 men; 1,885 women	Leukemia Presumed EMF>0.3 μT 1.64 (1.2-2.2) No significant increases for other cancers
Kuijten *et al.* 1992	New Jersey, Delaware, Pennsylvania	Workers in all occupations with children having astrocytoma	CC	163 children	EMF exposure during pregnancy Definite exposure 1.1 (0.4-3.1) Probable exposure 1.7 (0.7-4.4)

TABLE 5-2. SUMMARY OF EPIDEMIOLOGIC STUDIES OF PRESUMED OCCUPATIONAL EMF EXPOSURE AND CANCER INCIDENCE (continued)

Investigator and Date	Site	Workers and Exposure Type	Type of Study	Number of Cases or Subjects	Diagnostic or Occupational Risk Examined and Odds Ratio or Risk Ratio (95% Confidence Intervals)
Loomis 1992	24 states in USA	Cases of male breast cancer: 19 yr of age or more in 1985-1988	CC	250 male breast cancer cases	Electrical occupations All ages (4 cases) 0.9 Under age 65 (3 cases) 2.2 (0.6-7.8) Telephone worker (1 case) 9.0 (0.9-88.7) Early age and telephone work suggested: too few cases for significance
Tynes *et al.* 1992	Norway	Male electrical workers	SIR	37,945 workers	Leukemia 10 or more yr work 1.41 (1.10-1.76) Radio & TV repair 3.18 (1.03-7.43) Power line work 1.90 (1.01-3.24) Brain tumors Railway track walkers 2.20 (1.10-4.18) Male breast cancer Electric transport work 3.96 (1.08-10.14)
Matanoski *et al.* 1993	New York City	American Telephone and Telegraph (AT&T) employees	CC	124 leukemia deaths 1975-1980	All exposed workers 1.6 (0.5-49) >median EMF exposure 2.5 (0.7-8.6) With 15 yr latency 6.6 (0.7-58) Central office technicians 3.0 (0.6-15)
Sahl *et al.* 1993	California	Southern California Edison Company utility workers	CC	36,221 workers	EMF exposure estimate based on magnetic field measurements of present-day jobs -- no significant elevation of cancer risks Lymphomas (all electrical workers) 1.25 (0.68-2.31) Leukemia (>5 μT exposure) 1.30 (0.87-1.92)

*Corrected occupational categories as given in *Lancet* 2(8601):48, 1988.

Abbreviations:

ALL	Acute Lymphocytic Leukemia	AML	Acute Myelogenous Leukemia
CC	Case Control	CLL	Chronic Lymphocytic Leukemia
CML	Chronic Myelogenous Leukemia	PIR	Proportional Incidence Ratio
PMR	Proportional Mortality Ratio	RFU	Retrospective Follow-Up
SIR	Standardized Incidence Ratio		

Evaluations and reviews of these studies have largely emphasized the tentative nature of any conclusions that may be drawn from them (Aldrich and Easterly 1987; Ahlbom 1988; Brown and Chattopadhyay 1988; Coleman and Beral 1988; Czerski 1988; Knave 1988; Creasey and Goldberg 1989; Repacholi 1990). A minority of scientists have reached the conclusion that the epidemiologic and experimental data are so flawed that there is little reason to consider EMF exposure a potential human health hazard (see, for example, Michaelson 1987). Most scientists, however, would interpret the EMF epidemiologic studies as suggestive, rather than conclusive; indicating a possible, but not a clearly defined, human health risk from EMF. Estimates of significantly increased risk in each individual study are frequently small enough that results could easily be explained as statistical artifacts. Many scientists are also reluctant to accept the epidemiologic results at face value, because, at the present time, there is no unequivocal confirmation of cancer initiation or promotion by ELF EMF in an animal model system, and no plausible mechanism has clearly been demonstrated (Goldberg and Creasey 1991). However, the cumulative weight of many epidemiologic studies, most of which have suggested increased risks of similar but marginal magnitude, has stimulated public concern, and led to a modest but significant increase in worldwide EMF health effects research in the low frequency range. In using high-speed rail transport systems, the general public and electric rail workers would be exposed to ELF EMF which is similar to that produced by power distribution and electric power use in industrial applications; therefore, this body of literature is considered relevant to safety concerns for electric rail transport.

At this time it is not clear what EMF characteristics are most important with respect to the increased risk estimates seen in epidemiologic studies. The implicit, but not experimentally proven assumption has been that time-averaged magnetic field intensity is the most biologically important characteristic of ELF EMF, and therefore, the most appropriate parameter to measure. However, it should be recognized that this assumption is based on indirect scientific evidence, coupled with a general lack of effects seen in long-term studies in which animals were exposed to static or ELF electric fields only. The results of a number of epidemiologic studies suggest that "wiring code" or "distance from source" correlates with risk of cancer in residential studies, and "years of exposure" in electrical occupations correlates with risk of cancer in occupational studies. Wiring code is generally considered a surrogate measure of time-averaged magnetic field intensity. However, the recent study by London *et al.* (1991), in which both codes and 24-h magnetic field measurements were recorded, showed a significant correlation between wire code and risk, but only a weak and not statistically significant correlation between increased risk of cancer and measured magnetic field intensity. If these results are accurate, they indicate that wire code provides a surrogate measure of some field exposure characteristic other than 24-h average magnetic field intensity; such as number of transient changes in field characteristics with time, major surges, exposure at a limited set of frequencies, or average exposure over a longer time period. If so, the simple average intensity metric may not be a useful parameter to assess possible hazards associated with EMFs from advanced rail transport systems or power delivery systems (Bowman *et al.* 1991).

Electric railway and transit workers constitute a relatively small subgroup of total workers engaged in what may be loosely defined as "electrical" occupations. As noted earlier, there have been few epidemiologic studies that have considered them explicitly as a distinct occupational category. Utility workers employed in electrical switchyards or substations are the electrical workers most likely to be exposed to the rapid switching and relatively high intensity of EMF characteristic of occupational exposures in rail transport systems. For this reason, in the following discussion of data from epidemiologic and human health studies, we have emphasized those results which have been reported for substation and switchyard workers.

5.2 GENERAL EFFECTS ON PHYSIOLOGY AND BEHAVIOR

Adverse effects on general health, while raising less public concern than enhanced cancer risks, could nevertheless have an even greater impact on the safety of maglev trains by affecting the performance of train operators. There are a number of reports in the literature describing general health complaints of workers exposed to ELF fields, some of which, if valid, indicate a potential negative impact of EMF exposure.

Gamberale (1990) has reviewed the physiological and psychological effects of exposure to extremely low-frequency electric and magnetic fields in humans. The threshold for perception of an ELF electric field is approximately 5-15 kV/m, and perception of magnetic fields (as magnetophosphenes) occurs in excess of 100 G at frequencies over 10 Hz. In other experiments, humans have detected magnetic fields as low as 30 G (for 10 Hz pulsed fields), and as low as 5 G for "sweeping magnetic fields." The first reports of adverse human health effects of lower level ELF EMF exposures came from the former Soviet Union in the early 1960s. Several studies of workers in high-voltage switchyards (exposed to electric fields up to 26 kV/m) reported subjective symptoms of central nervous system dysfunction, and physiological symptoms such as hematological changes, sinus arrhythmia and tachycardia, and abnormalities in electroencephalographic patterns (see for example Asanova and Rakov 1966). A number of subsequent studies were performed in western countries (e.g. Strumza 1970; Knave and Floderus 1988), and most failed to confirm these effects. Health effects reported in the Soviet studies may be attributable, at least in part, to other factors in the work environment, such as exposure to solvents, or synergy with environmental pollutants. However, a number of studies undertaken in western countries have described an association between proximity to high voltage transmission lines and an increased prevalence of depressive symptomatology (Reichmanis *et al.* 1979; Perry *et al.* 1981; Haupt and Nolfi 1984; Dowson *et al.* 1988; Haysom *et al.* 1990). In one such recent study (Poole *et al.* 1992), the prevalence odds ratio for depressive symptoms was calculated as 2.4 (1.3-4.2 95% confidence interval (CI)), and for non-migraine headache, 1.5 (0.8-3.1 CI). An association between EMF and depression is not unreasonable, given the reports of an effect of EMF on pineal function and circadian rhythms (to be described in Sections IV C and VI A), since seasonal affective disorders also may be related to disturbed circadian rhythms (Lewy 1989). McMahan (1992), who has commented that most studies of depressive symptomatology have suffered from the twin problems of inadequate characterization of EMF exposures and unstandardized self-reported measures of depression, is carrying out a study involving on-site interviews and measurements aimed at avoiding these problems.

Gamberale (1990) has also reviewed laboratory experiments, mainly by scientists in Germany, which have documented effects of ELF EMF on human behavior, hematopoiesis, and the nervous system. Exposure to 2.5 V/m 10 Hz electric fields was reported to shorten the circadian rhythm by more than one 1h, and shielding from the geomagnetic field prolonged the circadian rhythm by about 20 minutes (min). In these experiments, exposure to higher intensity static magnetic and electric fields (up to 600 V/m) had no effect on circadian rhythm. In another series of experiments, human volunteers were exposed to 1-20 kV/m for periods of up to 5 h with only minor changes within the normal physiological range in some blood cell variables and a slight positive effect on fatigue in a psychomotor task. Other experiments involving exposure to 50 Hz magnetic fields (3 G) and exposure to electric fields of up to 20 kV/m were negative. Some field-related effects have been reported in studies from the United States. Subjects exposed for 6 hr to 9 kV/m and 190 mG showed changes in evoked potentials after acoustic and optic stimuli, and a field-related decrease in resting heart rate. In studies conducted in England, exposure to a 50 Hz field equivalent to 36 kV/m, produced changes in mood and a decrement in performance of a reasoning task. A recent study which evaluated the acute effects of exposure to ELF EMF in line workers (mean exposure to 2.8 kV/m and 233 mG), showed no significant effects attributable to field exposures. Gamberale concluded that the general impression to be gained from this research is that ELF EMF exposure does not constitute a health hazard for the general public or for the occupationally exposed worker, at least with respect to acute physiological and behavioral effects. However, questions of association with an increased risk of cancer, increases in genetic defects, or abnormal pregnancies cannot be resolved on the basis of present evidence. Some of the biological responses reviewed by Gamberale will be discussed in more detail in the following sections.

In a recent report on two studies of office workers with complaints of dermatologic symptoms associated with video display terminals (VDT), Arnetz *et al.* (1992) identified elevated levels of stress-sensitive hormones (catecholamines, thyroxine and prolactin) and accentuated psychophysiological reactions (including dissatisfaction with utilization of their abilities) during the workday among these subjects, but not in those with similar work experience, personality, and medical history who did not have skin symptoms. The authors hypothesized that the symptomatology constituted a stress syndrome (Techno Stress) involving metabolic, physiological and psychological elements, in which the physical environment and stress responses acted as unconditioned stimuli, and the VDT environment was the conditioned stimulus. According to this view, the VDT EMF emissions *per se* need play no biological mechanistic role in the dermatologic condition.

5.3 NEUROENDOCRINE EFFECTS

Although the body of Soviet studies reported such acute effects as listlessness, excitability, headache, loss of sex drive, drowsiness, and fatigue among electrical switchyard workers, other studies on substation and transmission line workers in Canada, England, France, West Germany, Italy, and the United States have failed to confirm these effects (Sulpor 1979). Epidemiologic data on 53 substation workers with more than 5 yr of exposure to electric fields of 400 kV were compared with data for a matched reference group of 53 nonexposed workers at the same power stations in Sweden, to investigate the possibility of chronic health effects resulting from high-voltage exposure (Knave *et al.* 1979). The investigation included effects on the nervous system, the cardiovascular system, the blood, and fertility. The results showed no significant differences between the exposed and reference groups as a result of long-term electric field exposure. In an acute health effects study of 26 experienced Swedish linemen (ages 25-52), Gamberale *et al.* (1989) found no significant effects on reaction time, complex reaction time, perceptual speed, short term memory, encephalographic recordings (EEG), or blood hormone levels (levels of thyroid stimulating hormone, luteinizing hormone, follicle stimulating hormone, prolactin, cortisol, testosterone, and neopterin) which could be related to measured field exposure. Mean exposure of linemen to ELF EMF during a simulated work day was 2.8 kV/m (range of 2.1-3.6 kV/m) for electric fields, and 233 mG (range 147-248 mG) for magnetic fields.

Animal experiments (discussed in section VI) have indicated that ELF EMF can function in a manner analogous to a strong light stimulus, blocking or delaying the normal nocturnal peak of pineal melatonin synthesis. The only study to examine this effect directly in humans was an electric blanket study conducted at Battelle Pacific Northwest Laboratories. Wilson and coworkers exposed 42 human volunteers to fields from several different types of electric blankets producing different ELF EMFs, and followed the long-term effects on nocturnal melatonin peaks as measured by urinary 6-hydroxy melatonin sulfate (6-OHMS) excretion (Wilson *et al.* 1988; 1989). Results indicated a greater pineal-suppressive effect among certain subjects using a blanket design (continuous polymer wire) that has a shorter duty cycle, and consequently, subjects the user to more frequent on/off events and 50% higher magnetic field levels (Wilson and Anderson 1989). This result is consistent with observations that rats show a greater inhibition of nocturnal melatonin peaks when exposed to interrupted (60 s on/ 60 s off) 60 Hz EMF than when exposed to a steady 60 Hz field (Wilson *et al.* 1990).

Intermittent exposure of healthy human volunteers to combined electric and magnetic fields (9 kV/m, 200 mG) in a sophisticated environmental exposure system at the Midwest Research Institute has been shown to produce statistically significant alterations in cardiac interbeat interval (slowing of heart rate) and psychological effects (alterations in evoked response) which seem to depend primarily on the magnetic component of the EMF (Graham *et al.* 1988; 1991a). Further, there is significant variation in the response to intermittent magnetic fields in different individuals, depending in part on the individual's heart rate prior to exposure (Graham *et al.* 1991b). These effects fall within the range of normal physiological variations (e.g., effects of mild exercise or fatigue), and are not considered cause for concern as adverse health effects. However, in contrast to the dramatic but poorly documented reports of psychophysiological responses in the earlier literature, these effects represent well-documented human responses to ELF magnetic fields. Such responses could have subtle negative effects on human performance; or could produce a much stronger effect in interaction with other stressors, or in particularly susceptible individuals.

5.4 REPRODUCTIVE AND TERATOLOGIC EFFECTS

Nordstrom *et al.* (1983) reported results of a reproductive health survey of 483 employees and former employees of Swedish power plants. Exposure was estimated with respect to 3 types of occupation, (groups working at high-voltage switchyards; construction or repair of switchyards and transmission lines; and other tasks such as working in offices and stores) and electric field exposure (less than 70 kV; 130-200 kV; and 400 kV). Pregnancies occurring when the father was not employed at the power plants or when he was working exclusively with 380/220 V, served as a control group. A total of 880 pregnancies was included in the study. The frequency of pregnancies with a normal outcome varied from 87 to 90% (average, 88%) among the three groups of voltage exposure. However, there was a significantly ($p<0.05$) lower frequency of normal pregnancy outcome (81%) when the father had been working in high voltage switchyards as compared to the other occupations (89 and 92%) or to the control group (87%), which resulted almost exclusively from a statistically significant ($p<0.001$) increase in the frequency of congenital malformations (12/119 children born to switchyard workers vs. 5/294 children born to other personnel and 9/225 children in the control group). No child with a malformation born earlier than 1953 was found. The distribution of malformations by time was very variable: 14.3, 2.1, and 16.7% for 1953-1960, 1961-1970, and 1971-1979, respectively. Males working in high voltage switchyards experienced more fertility problems (24/90) compared to employees in other occupations (8/74). There was no correlation between the confounding factors analyzed and the results of the study. Others have reported increased abnormality rates in children with fathers working in electrical occupations. Olshan and coworkers (1988) analyzed 22,192 cases of birth defects identified during 1952-1973 using the population-based Health Surveillance Registry in British Columbia, and found an increased risk of upper limb reduction defects among several occupational groups, including electricians and electronic equipment operators.

There has been some controversy over reports by Wertheimer and Leeper (1986; 1989) that heating methods such as electric blankets or ceiling heating cables might generate ELF EMF (100 V/m, 15 mG and 10-50 V/m, 10 mG, respectively) capable of inducing fetal abnormalities or loss. In these surveys, there was evidence that some seasonal factor, either the heater EMF or some factor correlated with it, increased fetal loss, and led to higher incidence of low birth weights (46% in electric blanket users versus 21% in controls) and congenital abnormalities (2.6 versus 0.3%). Since both blankets and ceiling heating showed the effect, it was concluded that the confounder of local heating was not responsible. The findings of Wertheimer and Leeper received support from a recent case-control study of electric blanket usage during pregnancy, in which 986 women with abnormal pregnancy outcomes (68% spontaneous abortions) were age-matched with 975 healthy pregnant women in Hangzhou, China. Spontaneous abortion was associated with electric blanket usage during the first trimester, but not in middle or late pregnancy; the uncorrected odds ratio (OR) being 1.95 (1.31-2.90 CI). When allowance was made for drug use during early pregnancy, or exposure to noise or chemicals, the adjusted ORs were 1.80 (1.22-2.64 CI), 2.13 (1.43-3.15 CI), and 2.12 (1.41-3.17 CI), respectively (Yong *et al.* 1992). Dlugosz *et al.* (1990; 1992) carried out a case-control study, using data from the New York Congenital Malformations Registry, for 542 mothers with infants exhibiting cleft palate, cleft lip, anencephalus and spina bifida. Relative to nonusers, conditional logistic relative risk estimates of giving birth to malformed infants for women who used electric blankets or heated waterbeds were nearly identical and below unity (0.7-0.9), even with allowance for confounders. Although these results are different from the findings of the two previous studies, it should be noted that these abnormalities are not lethal to the fetus, and may not occur in parallel with effects that lead to spontaneous abortions. As discussed in Section IV C, electric blanket usage exposes the individual for prolonged periods to fields that undergo frequent on/off switching, and has been reported in studies with some types of blanket to produce disturbances in circadian rhythms of pineal activity and melatonin production (Wilson *et al.* 1989), which might adversely affect the endocrine environment of the fetus. Design changes in electric blankets available in the U.S. have reduced magnetic field levels by 92.4-96.7% (Casamento *et al.* 1992). These changes may have minimized or eliminated the effects on melatonin levels produced by electric blankets, but this has not yet been verified in a follow-up study.

5.5 MUTAGENIC EFFECTS

There are a few case reports in the literature suggesting mutagenic effects of occupational exposure to EMF, but most of these have been explained in terms of well-documented high field intensity effects. For example, Nordenson *et al.* (1988) followed up reports of increased rates of chromosomal aberrations in a group of 400 kV-substation workers. Measurements of the electric (E) field in the workplaces of 38 exposed men showed that most worked in E-field strengths below 10 kV/m; one was exposed to E fields in excess of 20 kV/m, 4 in the 10-15 kV/m range, 7 in the 5-10 kV/m range, and 7 below 5 kV/m. This was also the case for the controls. The highest rate of aberrations was found in a subgroup of workers exposed to a measured E-field strength of more than 10 kV/m (average of 3.9% metaphases, with 4/5 workers having 3.5% or more abnormal metaphases). The group of workers exposed at a measured E-field strength of under 5 kV/m had an abnormality rate of 2.9% metaphases with 2/7 workers having 3.5% or more abnormal metaphases. Since *in vitro* exposure of lymphocytes to transient electric currents produced similar results, the authors suggested that chromosome damage might be induced by spark discharges. Seven of the exposed group stated that they had experienced spark discharges during the previous few days, mostly localized to the hands and forearms.

5.6 SPECIALIZED HEALTH PROBLEMS

In specialized cases, otherwise innocuous EMF environments could produce serious negative health effects in certain individuals. The best documented and understood example involves electrical interference with certain (older) models of electrical cardiac pacemakers. Kaye *et al.* investigated the effects of injected 50 Hz AC on the function of 12 different cardiac pacemaker models observed in 18 patients with implanted unipolar VVI units, and a group of 10 patients with temporary transvenous pacing electrodes. With most implanted pacemakers exposed to a gradually increasing injected current, there was an initial phase of normal pacemaker function followed by a variable period of mal-sensing, inappropriate pacing, and intermittent complete inhibition; most of the pacemakers reverted to interference mode in the current range of 29-250 uA (Kaye *et al.* 1988). Butrous *et al.* (1983) described two cases of pacemaker interference in electrical substation workers. The first case involved a 32-yr-old man with a Telectronics 174 programmable pacemaker who noted an abnormal thumping sensation in the chest whenever he went to certain areas of a 275/132 kV substation near high voltage conductors. During electrocardiographic monitoring, the pacemaker reverted to the interference mode when the patient was standing on a grounded aluminum plate in a high intensity power frequency field sufficient to induce a corporeal current of 41 μA or more (field strength 2.5 kV/m with the arms raised and 3.0 kV/m with the arms at the side). In a facility that produced a high intensity 50 Hz electric field, the pacemaker reverted to interference mode when the field reached a 2 kV/m (unperturbed value measured at 1.8 m above the ground), inducing a corporeal current of 25 μA. The second case involved a 57-yr-old man with a Cordis 334A pulse generator pacemaker. Field strengths above 13 kV/m, with the patient standing with both arms at his side, produced inappropriately slow irregular pacing (with pacemaker impulse intervals up to 2.5 s) lasting for a few seconds and followed by regular pacing at a rate of 40-50 pulses/min. These findings were consistently reproduced when the patient was retested in a typical working environment in a 400/275 kV substation. In spite of an increase in potential sources of electromagnetic interference, a recent review of hazards to users of cardiac pacemakers indicated that risk has tended to decrease because of improved pacemaker designs in the past decade (Sager 1987). Even with the older designs, serious pacemaker malfunction has been relatively rare. A Norwegian survey of 2200 patients with pacemakers uncovered only 10 patients who were affected by electromagnetic interference, and none had serious or fatal outcomes (Ohm 1976).

6. CLINICAL AND EPIDEMIOLOGIC STUDIES OF HUMAN EXPOSURE TO STATIC MAGNETIC FIELDS (MRI AND RESEARCH FACILITIES)

Concern with possible human health effects of high-intensity static magnetic fields has primarily centered on the clinical use of nuclear magnetic resonance imaging (MRI) devices. Through a long series of animal studies and patient reviews, the U.S. Center for Devices and Radiological Health, Food and Drug Administration (FDA), has recently reclassified MRI devices from Class III (highest level of premarket regulation) to Class II (medium level of premarket regulation), indicative of a degree of confidence in the safety of the devices at the field levels used clinically (Athey 1990). As a part of the reclassification process, FDA developed a set of "Safety Parameter Action Levels" which set forth guidance on levels of static magnetic fields, dynamic magnetic fields, and radiofrequency magnetic fields which FDA considered to be below the level of concern. Similar evaluations and recommended exposure limits have been developed in the U.K. by the National Radiological Protection Board (Saunders and Sienkiewicz 1990). In view of the fact that certain maglev configurations may generate static magnetic fields of 60-600 G, which approaches the order of magnitude of those produced during low-field MRI (500-2,000 G), information about MRI fields and the regulations governing them is relevant.

Prato *et al.* (1986) reviewed potential hazards associated with MRI for both patients and operating personnel, ranking the possibility of bioeffects associated with exposure to RF fields, static magnetic fields or time-varying magnetic fields tenth in a series of eleven concerns. Some of the concerns raised in this article are relevant to rail installations: (1) ventricular fibrillation due to cardiac pacemaker malfunction when the external magnetic field is in the range 7-17 G; (2) internal trauma due to torque on ferromagnetic metallic implants; (3) injury caused by flying ferromagnetic objects in a magnetic field gradient; and (4) electrical burn and shock hazards associated with any high current electrical equipment. A survey of reproductive health among female MRI operators, from whom data on 1421 pregnancies was obtained, suggested that apart from a slight, non-significant increase in the relative risk for spontaneous abortion (1.3, with 95% confidence interval of 0.9-1.8), there was no substantial increase in adverse reproductive outcomes (Kanal *et al.* 1992). Exposure of normal male volunteers to MRI of the skull between the hours of 1 and 2 a.m. disclosed no alteration in the dark-induced rise in plasma melatonin levels seen on exposure to a mock MRI procedure involving listening to a recording of the scan, under the same dim lighting conditions. Exposure to bright light plus mock MRI conditions led to the characteristic light-induced fall in plasma melatonin (Schiffman *et al.* 1992).

Limited health hazard evaluations and health monitoring studies have been initiated with workers exposed to static magnetic fields in research or industrial facilities. At the Fermi National Accelerator Laboratory in Batavia, Illinois, static magnetic field exposure was low compared to radiofrequency (RF) and ionizing radiation from the atomic particle accelerator systems (Moss and Boiano 1988). High static magnetic field exposures have been documented in industrial settings. For example, in two chlor-alkali facilities static magnetic fields ranged from 1.0 to 173.2 G, with an average of 82.3 G and from 4.1 to 182.9 G, with an average of 46.8 G (Pastides *et al.* 1991). Health surveys with these workers have not indicated any acute effects, but long-term exposure effects are unknown. As has been noted in other comprehensive assessments of EMF exposure in "electrical occupations," workers are usually exposed to a complex and variable set of potentially hazardous factors, and it may be very hard to factor out the contribution from exposure to EMF without the use of personal recording field meters (Bowman *et al.* 1989).

7. ANIMAL HEALTH EFFECTS AND BEHAVIORAL STUDIES

Experiments carried out in model animal systems can shed light on the characteristics of potentially harmful EMF and on the mechanisms underlying any biological interaction, because they permit manipulation of the EMF environment in a way which is not possible in the human environment. Unfortunately, until recently most studies utilized steady, unvarying fields, usually only with an electric component, on the assumption that such fields generated by power transmission lines were the chief environmental hazard. A recent study suggests that this is still the layperson's view of EMF risk, and presents a challenge for any public education program in the area (Delpizzo and Elliott 1992). As a result of this bias, there is little information available concerning the biological effects of the variable and transient exposures to combined electric and magnetic ELF fields actually experienced by most humans. Despite this limitation, experimental data from studies of ELF EMF at 50 or 60 Hz may provide some information of relevance, while information from other studies involving high-strength magnetic fields, whether static or time-varying, is relevant to maglev train operation, as well as to other exposures such as those occurring during MRI.

7.1 EMF AS A STRESSOR - ENDOCRINOLOGIC EFFECTS

A concept has developed that seeks to explain the biological interactions of EMF on the basis that such fields act as stressors, setting up changes in the neuroendocrine axis that lead to a range of biological effects. Stress is known, for example, to produce increased plasma levels of adrenocorticosteroids, which create changes in physiological functions such as heart rate, and also have been associated with decreased immune response, one of the secondary effects of which could be an enhanced rate of tumor growth (Riley 1981).

Studies aimed at demonstrating activation of the hypothalamo-hypophyseal-adrenal axis by EMF have produced equivocal results. A report from the Soviet Union (Udintsev *et al.* 1986) indicated that in rats exposed to an alternating magnetic field (50 Hz; 200 G) the hypothalamo-hypophyseal-adrenal system was activated. Plasma concentrations of 11-hydroxyketosteroids and ACTH were elevated, as were plasma and tissue levels of free fatty acids and phospholipids, but after prolonged, repeated exposures the activity of the endocrine axis was depressed. There was evidence of increased lipid peroxidation after chronic exposure to EMF. Such an activation does indeed resemble a type of stress reaction. Another piece of evidence suggestive of a stress reaction in rats exposed to 60 Hz electric fields, is the secretion of porphyrin by the Harderian glands (Leung *et al.* 1988; 1990). That the effect is not restricted to rats was shown by the occurrence of similar activation of the adrenals and thyroid in mice (Kartashev and Ivanova 1988). In contrast, Quinlan *et al.* (1985) failed to show generalized activation of the hypothalamo-hypophyseal-adrenal axis, although the level of growth hormone was elevated in exposed rats. Ragan *et al.* (1983) and Michaelson and Lu (1988) were also unable to detect a stress reaction. Studies carried out with adrenal tissue in vitro, however, indicated that 60 Hz fields, while not themselves directly altering steroidogenic activity, greatly stimulated the response to ACTH (Lymangrover *et al.* 1987). Prolonged exposure of rats to strong 60 Hz electric fields slightly lowered the plasma levels of corticosterone, together with those of testosterone and prolactin, but effects on thyroid activity and follicle-stimulating hormone were equivocal (Free *et al.* 1981). Other endocrinologic effects that have been reported include evidence based on tissue iodine contents of suppressed thyroid activity in rats exposed to a 50 Hz, 1.1 G field for 20 or 30 days (Marsakova 1982), and a reduction in insulin release by isolated rabbit islets of Langerhans (Jolley *et al.* 1983).

Most interesting of all the endocrinologic findings have been those regarding pineal function. Exposure of rodents to 60 Hz EMF fields can abolish the pineal circadian rhythms for the synthesis and secretion of melatonin (Wilson and Anderson 1989; Wilson *et al.* 1985; 1986; 1989; Groh *et al.* 1988); 60 Hz electric fields also reduce the nocturnal peak levels of this hormone (Leung *et al.* 1988), and night-time urinary excretion of 6-hydroxymelatonin (Sasser *et al.* 1991). These pineal changes are correlated with altered circadian rhythms of activity and metabolism (Groh and Readey 1990). Yellon (1991) exposed Djungarian hamsters to a 60 Hz MF (+1 G horizontal component) for 15 min beginning 2 h before lights off, and reduced the duration of increased melatonin in the pineal at night and blunted the nocturnal rise in serum melatonin ($p < 0.05$ compared to controls). This result is remarkable because exposure occurred during the daylight period, producing an effect which lasted at least six h into the dark period (while pineal effects on rats occur with EMF exposure during the dark period). On the other hand, sheep penned beneath a 500 kV transmission line for up to 10 months have shown no sign of disturbed circadian rhythm or melatonin secretion (Chartier *et al.* 1991), while findings with baboons exposed to combined electric and magnetic fields (30 kV/m and 1 G with different rates of onset) have been inconsistent (Rogers *et al.* 1991). Recent Battelle studies with rats also have found that the trend of inhibition of nocturnal melatonin is not always consistent enough to reach statistical significance (Sasser *et al.* 1992). Some of this inconsistency may result from dependence of the effect on factors such as frequency of field cessation or reversal (Reiter *et al.* 1990; Lerchl *et al.* 1991; Wilson and Anderson 1989), or the phase of melatonin production during which exposure occurs (Reiter *et al.* 1992). The implication for human health effects depends on which animal model (the laboratory rat with its nocturnal sensitivity, or the Djungarian hamster, with its daylight sensitivity) is more similar to human physiology with respect to circadian physiology.

In summary, the most consistent and potentially significant of the hormonal responses to ELF EMF exposure appears to be the reported abolition of the pineal circadian rhythm for melatonin synthesis and secretion. Interference with circadian rhythms potentially could have major repercussions on human work performance, and research to establish definitively whether or not this effect occurs in humans in response to the types of EMF likely to be encountered in occupational environments, such as electrified transport systems, is vital. In addition, melatonin plays the role of an immunomodulator by stimulating immune responses (Maestroni *et al.* 1987), and has also been implicated in the direct control of cell proliferation and as a suppressor of the growth of transplanted tumors (Reiter 1988; Blask 1989).

7.2 EFFECTS OF ELF EMF ON THE IMMUNE SYSTEM

It has been suggested that EMFs acting at the cell membrane may modulate the function of the immune system (see review by Budd and Czerski 1985). The literature on the interaction of EMFs with the immune system is highly conflicting. Only data from exposure of whole animals to 50 or 60 Hz electric or electromagnetic fields can be said to show any consistency, and here the picture is one of relatively small or null effects.

Russian investigators (Liubchenko 1982) reported that chronic exposure of rats to 50 Hz fields (1-15 kV/m) caused only a transient increase in blood complements (proteins that react with antigen-antibody complexes to lead to cell lysis and other immune functions), while human volunteers exposed to 12 or 15 kV/m exhibited transient elevations in complement titer. In a series of experiments in which mice were exposed to 60 Hz fields at 100 kV/m for 30 to 150 days, Morris and his colleagues found no significant perturbation of the immune system in terms of primary antibody response or mitogen stimulation of spleen cells. An increased mitotic index for phytohemagglutinin-stimulated spleen cells from exposed as compared with sham-exposed mice was not statistically significant (Morris and Phillips 1982; Morris 1985). This study was extended to rats, where no major changes in cell-mediated immune responses were observed (Frazier *et al.* 1988; Morris *et al.* 1989). In contrast, when female sheep were penned beneath a 60 Hz, 500 kV power line for 2 to 6 months, there was a significant reduction in mitogen-stimulated IL-1 production, reduced antibody response to Lepto-5 antigen, and enhanced dermal infection with fungal soil organisms (McCoy *et al.* 1992).

Data obtained by exposure of isolated components of the immune system to ELF EMFs *in vitro* have been conflicting. A series of reports have claimed that exposure of human lymphocytes to pulsed EMFs enhances their response to mitogens such as phytohemagglutinin, as measured by DNA synthesis (Hellman *et al.* 1985; Emilia *et al.* 1985; Cantini *et al.* 1986; Franceschi *et al.* 1986; Cadossi *et al.* 1986). On the other hand, Conti *et al.* (1983), using square wave pulses at 1 to 200 Hz, reported that lectin-stimulated mitogenesis of human lymphocytes was inhibited. Bersani *et al.* (1992) found that whether the effect was stimulatory or inhibitory depended on the physical characteristics of the EMF, while Cossarizza *et al.* (1989) could find no effect of pulsed or rotating fields. Studies with sinusoidal ELF EMFs have generally shown modest depression of various components of the immune process. Phillips (1986) found that 60 Hz magnetic fields alone, or combined electric and magnetic fields, inhibited natural killer-cell-induced cytolysis of irradiated Colo 205 cells in vitro. Lyle and his group also have reported inhibition of the allogeneic cytotoxicity of a normal murine T-lymphocyte cell line CTLL-1 by 60 Hz sinusoidal electric fields (Lyle *et al.* 1988). A 50 Hz electric field (5 kV/m) was also reported to inhibit lymphocyte proliferation (Cossarizza *et al.* 1992). Stimulatory effects of 15 Hz, 1 G fields reported in human immune cells include proliferation of activated B- and T-cells (Mehta *et al.* 1991), and release of IL-2 by T-cells (Blackinton *et al.* 1992). Finally, Winters (1986) summarized a project involving human and canine lymphocytes by concluding that ELF EMFs had no effects on ligand receptors, immunoglobulins, mitogen response, or the synthesis of DNA, RNA, and protein. He did find, however, that cultured human colon cancer cells showed a mitogenic response, increased transferrin receptor contents, and resistance to natural killer cells after exposure; DNA synthesis in human skin fibroblasts was elevated after exposure to a 60 Hz magnetic field.

This variability in response may arise from several sources apart from the difference between pulsed and simple sinusoidal waveforms mentioned above. Distinct "window effects" for frequency and intensity, somewhat analogous to action spectra, have been identified. Thus, Cadossi *et al.* (1986) reported that inhibition of the lectin response occurred in 10 mV fields, in contrast to the stimulation seen at other intensities, and Conti *et al.* (1985) found that inhibition did not take place at various combinations of frequencies for particular lectins. Similarly, Franceschi *et al.* (1986) obtained a bimodal response at low phytohemagglutinin concentrations in which the effect of EMF was inhibitory rather than stimulatory. Even the components of the EMF complicate the data: Morris and McClanahan (1986) reached the conclusion that a 60 Hz electric field with a 0.05 G magnetic contaminant was needed to enhance the mitogenic response of lymphocytes, when they were unable to find an effect with 60 Hz pure electric or magnetic fields alone.

In spite of the large amount of experimental data obtained, it is difficult to arrive at any firm conclusions regarding the action of EMFs on the immune system. Apart from the sheer inconsistency of the results obtained using what appear to be the same systems, the use of multiple exposure parameters, the explanation of unexpected dose/response relationships as window effects, and the many different measures of immunity that have been followed, present major difficulties in interpreting the data.

7.3 EFFECTS ON REPRODUCTION AND DEVELOPMENT

A number of studies have investigated the teratogenic potential of ELF EMF, primarily using chicken embryos or mammalian fetuses exposed in utero. The results of these studies are strikingly variable; many have been negative while apparently replicate experiments showed a significant teratogenic effect. This inconsistency has been interpreted either as random biological variation (noise) or as a valid teratogenic effect which is strongly dependent on specific field characteristics that are not adequately understood or controlled.

The limited number of chronic exposure experiments that have been done with mammals using morphology and early postnatal behavior to study first or second generation offspring raised in high electric fields have been predominantly negative. They have been reviewed by Creasey and Goldberg (1989). In essence, sinusoidal fields have had no effect in rats, but Hanford miniature swine did show a marginally significant increase in the number of musculoskeletal malformations in the offspring of exposed sows (Sikov et al. 1987). Tests of neuromuscular function in the apparently normal exposed F2 progeny from an earlier replicate of this experiment failed to demonstrate any functional differences (Lovely, Creim, and Phillips 1982).

A few have reported slightly decreased growth rates in animals exposed prenatally or perinatally to electromagnetic fields. Thus, young rhesus monkeys from 1 to 54 months of age, chronically exposed to extremely low frequency electric and magnetic fields demonstrated a significantly lower body weight and higher testosterone levels in exposed males compared with the control group, but no apparent difference in weight or steroid hormone concentrations in the females (Lotz and Saxton 1984). Small but significant decreases in maternal body weight and lower rates of weight increase in male but not female pups were reported for exposed rats, and were interpreted as a response to chronic stress (Sikov *et al.* 1988). Offspring of gravid laboratory rabbits, chronically exposed to a strong 50 Hz electric field during gestation and/or during the first six weeks postpartum, were found to have small endocrine differences associated with a mild stress response (Portet and Cabanes 1988). Mild stress effects may be a confounding factor in teratogenesis studies.

In contrast to the largely negative results with sinusoidal AC electric fields, two Swedish studies have suggested a teratogenic effect associated with pulsed magnetic fields of the type produced by video display terminals (VDTs). Interest in this area was stimulated by reports of clusters of abnormal pregnancies and miscarriages among VDT operators, and field characteristics were chosen to simulate this exposure. A group from the Swedish Agricultural University reported a significant increase in the frequency of placental resorptions in C3H mice exposed to a 20 kHz sawtooth pulsed magnetic field with a peak field strength of 150 mG, suggesting an effect early in development (Frolen *et al.* 1987); while investigators from the Karolinska Institute, using the same strain of mice and apparently identical exposure conditions, found a significant increase in external malformations with no increase in resorptions or mortality (Tribukait *et al.* 1987). Mice exposed to 1 or 15 mG 100 Hz rectangular pulsed magnetic fields (rather than the sawtooth waveform) showed no change in the frequency of malformations. However, exposure of rats to similar pulsed magnetic fields by Stuchly *et al.* (1988) in Canada, and another teratological study using a 50 Hz homogeneous magnetic field (Brinkmann *et al.* 1988), found no enhancement of resorptions or abnormalities.

Experiments using chicken embryos represent the largest body of published work on the teratological effects of electromagnetic fields, much of it using nonsinusoidal and pulsed fields. Electric fields have generally been found to produce no effect (Graves 1982). Delgado's group reported up to a 78% incidence of gross morphological abnormalities produced in chicken embryos by exposure to weak low frequency magnetic fields during early development (Delgado *et al.* 1982). The incidence of abnormality was greater at an intensity of 12 mG than at either 120 or 1.2 mG, suggestive of an intensity-specific ("window") response. Attempts to replicate these results in other laboratories have been mixed.

In an attempt to resolve the contradictory data, the U.S. Environmental Protection Agency and the Office of Naval Research sponsored the "Henhouse Project," in which a single experiment was carefully replicated in six different laboratories around the world. The study used a blind design to avoid experimental bias, and signal generators that produced a reproducible field similar to, but not exactly like, the field used by Delgado. Six identical paired exposure and sham-exposure incubators were built and shipped to the six laboratories, and field measurements were made on site by the same experienced personnel (Wagner and Mantiply 1988). Abnormalities were evaluated in each laboratory using uniform criteria. Results were found to vary by laboratory; two of the six laboratories showed a significant increase in the proportion of abnormal embryos with exposure, while the others (including laboratories that had reported significant effects previously) did not. The increase in the proportion of abnormalities was significant for the project as a whole at $p = 0.001$ (Berman *et al.* 1990). Perhaps most important, however, is the finding that careful replication of exposure conditions and prevention of experimental bias do not insure replication of results between laboratories with this experimental system.

Three factors might explain much of the variability in this system. The first is the very critical time-dependence demonstrated by Martin (1988), where the first 24 h of incubation represent the sensitive period, no effects being demonstrated at later times. This time-dependence for EMF sensitivity has been further refined, to correlate it with the biological stage of late gastrulation (Ubeda *et al.* 1992). Second, the possibility of "window effects" operating in this system is illustrated by the studies of Chacon *et al.* (1989; 1992), who demonstrated the formation of abnormalities in embryos exposed to frequencies and combinations of fields associated with cyclotron resonance of particular ions - sodium or calcium. Third, the high degree of variance seen in these chicken embryos may reflect their inherent genetic variability. Attempts to develop inbred lines of chickens for experimental work have not been successful, probably because of recessive lethal mutations in the species, and birds of the same strain (e.g., white leghorns) are not necessarily genetically similar in flocks from different regions.

7.4 EFFECTS OF EMF ON INDUCTION AND GROWTH OF TUMORS

Although a number of such studies are underway, only one has yet been reported in which normal animals were exposed chronically to ELF EMFs and the spontaneous development of tumors was followed. In this study, 78% of mice exposed to a 250 mG, 60 Hz field for 418 days developed lymphoid hyperplasia, premalignant changes and thymic lymphoma, compared with 6% of controls; at 257 days the figure was 45% (Mikhail and Fam 1992). However, the low energy of ELF EMF makes it probable that if there is a real carcinogenic action, it is based on promotion or co-promotion, rather than on initiation.

A few studies have looked at EMF in this way, using a chemical carcinogen as the inducer. For example, Leung *et al.* (1988) have reported on the incidence of mammary tumors in rats exposed to 7,12-dimethylbenz(a)anthracene and 60 Hz (40 kV/m) electric fields and found a significant ($p<0.05$) increase in the number of tumors in the 60 Hz-exposed compared with sham-exposed rats. Mevissen *et al.* examined the effects of a 50 Hz, 1 μT (10 mG) magnetic field on the development of mammary tumors in female rats pretreated with 7,12-Dimethylbenz(a)anthracene (Mevissen *et al.* 1992). For several years, they reported that magnetic field exposure had no detectable effect on tumor incidence in this system, while measurements of serum melatonin levels in the same animals showed that the exposure conditions were sufficient to reduce nocturnal melatonin levels significantly. However, recently the same group obtained results suggesting an effect in at least one replicate of the above experimental design (Mevissen *et al.* 1993b), and a much stronger promoter effect using a new exposure system (Mevissen *et al.* 1993a); Loscher, personal communication). Their current experimental design allows exposure of 100 rats per experiment, and with exposure to a 100 μT (2 G) 50 Hz field there was a 50% increase in the mean number of rats with tumors ($p<0.03$) for weeks 8-13. The authors attribute the increased level of significance primarily to the larger sample size, noting that pervious studies showed the same trend, but used sample numbers which would not reveal increased tumor growth of less than 100%. McLean *et al.* described stimulation of early tumor development by 60 Hz magnetic fields (20 G, 6 h/day x 5 days/week, for 23 weeks) without increased total tumor yield, in the mouse skin model, with 7,12-dimethylbenzanthracene as inducer and a phorbol ester as promoter (McLean *et al.* 1991). Subsequent reports from this group indicated a significant increase in both the number of animals with tumors and the number of tumors per animal after 12 weeks of 60 Hz magnetic field exposure, but differences between EMF-exposed and control animals were no longer significant by 23 weeks (Stuchly *et al.* 1992). Most recently, this group has described a weaker effect of magnetic field exposure alone, and a possible promoter action with exposure to fluorescent light (McLean *et al.* 1993). This result would appear to explain away the copromoter effect of magnetic fields reported earlier, but experiments were done with a relatively small number of animals (48 animals per group) and are therefore subject to some statistical uncertainty. Other studies have failed to show any promoting action of 60 Hz magnetic fields on tumor induction by 9,12-dimethylbenzanthracene (Buntenkotter *et al.* 1990) or dimethylnitrosamine (Rannug *et al.* 1990).

In other cases, the growth of established tumors was studied in different experimental systems exposed to EMF. Pulsed magnetic fields inhibited the growth of spontaneous mammary tumors in C3H mice (12, 100, 460 Hz: Bellossi *et al.* 1988), of reticulosarcoma in rats (fluctuating EMF less than 200 kHz: Iur'ev and Krasnogorskaia 1980), of B16 melanoma in C57/Yellow mice (pulsed, 0.8 Hz, 1,000 G: de Seze *et al.* 1992), and of HeLa and mouse mammary tumor cell lines in vitro (100 Hz: Rius *et al.* 1985; pulsed 0-1.6 Hz, 0-1,800 G: Tuffet *et al.* 1992). The incidence of lymphomas initiated with X-radiation in CBA mice was increased approximately 8% by coexposure to a 150 mG, 20 kHz sawtooth magnetic field (Svedenstal, 1992, 7938). On the other hand, the growth of P388 leukemia in mice was not affected by 60 Hz magnetic fields (Thomson *et al.* 1988). Similarly, the growth of HeLa cells in culture was unaffected by 50 Hz ELF EMF (Adolphe *et al.* 1987). These studies with tumor lines constitute a test of tumor progression and growth, and it is interesting that ELF EMF does not appear to stimulate cell and tissue growth in the same manner as the pulsed EMFs used clinically. Clinical pulsed EMFs are generally repetitive burst patterns of various waveforms (sinusoidal, rectangular, sawtooth) delivered at low frequency intervals; e.g., 5 ms-wide bursts of 200 us-wide pulses delivered at 15 Hz (Marcer *et al.* 1984).

7.5 BEHAVIORAL EFFECTS

A number of long-term ELF EMF exposure studies have been conducted using behavioral endpoints. Extrapolating from animal behavior to human performance or psychological effects is always problematic, but perhaps less so for non-human primate animal models. A number of studies have been conducted in the baboon colony at the Southwest Foundation for Biomedical Research in San Antonio, TX. When a social group of eight male baboons was exposed to a 30 kV/m, 60 Hz electric field over three, six-week periods (12 h/day, 7 days/week), behavioral categories of passive affinity, tension, and stereotypy were most responsive (Coelho *et al.* 1991a). The observed behavioral differences indicated a stress response to the electric field, but it is not clear if these effects are harmful or permanent. More recent experiments by the same group have examined the effects of combined electric and magnetic field exposure. Analyses indicated that the behavioral responses of the animals exposed to two different combined field conditions (6 kV/m, 500 mG; 30 kV/m, 1 G) did not produce the levels or pattern of behavioral changes observed in earlier 30 kV/m or 60 kV/m electric field experiments (Coelho *et al.* 1991b; Orr and Rogers 1991; 1992).

A more controversial and problematic body of research literature exists regarding the ability of ELF fields to alter conditioned behavior in rats. A number of research workers have reported the ability of weak ELF electric or electric and magnetic fields to modify behavior, mostly functioning as a non-specific stressor degrading performance on learning tasks or increasing arousal. Rudolph *et al.* (1985) reported that short-term (4 h) exposure to a weak, 50 Hz electromagnetic field which reversed the natural horizontal component of the earth's magnetic field (0.2 G) 50 times/s, produced an increase in rearing behavior and ambulation that was interpreted as an increase in "non-specific excitability level" when the field was applied at the beginning of the light phase but not the dark phase. Thomas, Schrot, and Liboff (Thomas *et al.* 1986a; Liboff *et al.* 1989) reported that low-intensity magnetic fields altered the operant behavior of rats, however Stern and Laties (1990) were unable to reproduce the results using similar methodology.

Lovely (1988) has reviewed reports on the behavioral effects of exposure to extremely low frequency (ELF) electric and magnetic fields, primarily in the frequency range of 1-300 Hz, and offered the opinion that the toxicological orientation of much of the published research in this field is based on the missions of power industry and Department of Energy research programs to evaluate the health effects of 50 and 60 Hz fields. Indices of detection (ELF-induced arousal responses and changes in the level of activity following ELF exposure) or aversive behavior have been reported in rats after exposure to 50 or 60 Hz electric fields, but remarkably few robust behavioral effects have been reported. Those that have been reported probably relate more to the animal's perception of an electric field rather than to any neurotoxic effects.

In order to investigate possible long-term effects of EMF exposure on behavior, Sprague-Dawley rats were exposed or sham-exposed to combined vertical electric (60 Hz, 30 kV/m) and circularly polarized magnetic (60 Hz, 1 G) fields from the day of conception to eight days after parturition. The effect of this perinatal exposure on the operant behavior of the rats was evaluated (Salzinger *et al.* 1990). When observed as adults, rats consistently responded at significantly lower rates after a period of conditioning than did sham-exposed controls. These behavioral effects, while not necessarily indicative of a deleterious effect of ELF EMF exposure, are a lasting effect showing greater robustness over time and changing conditions than some of the short-term studies. The fact that it is the 60 Hz ELF modulation, rather than the magnetic field *per se*, which is responsible for such an effect, is suggested by a study in which perinatal exposure to a 100 kG static field for 8 h/day, days 12-16 post conception, had no effect on subsequent operant behavior testing (Bornhausen 1989). For some time, Adey, Bawin and their coworkers have suggested that ELF EMF has the potential to interact with electrical activity of similar frequency in the central nervous system, producing various alterations in electroencephalographic and circadian rhythms through changes in the ion conductivity of neural membranes (Adey and Bawin 1979).

Thomas and coworkers (Thomas *et al.* 1986b) demonstrated that operant behavior in rats could be affected by a combination of a 60 Hz magnetic field and a very small static magnetic field (0.26 G, about half that of the geomagnetic field). Rats exposed to this combination for 30 min consistently exhibited changes in the rate and pattern of response during the differential reinforcement of the low rate (DRL) component of a multiple fixed ratio DRL reinforcement schedule. By contrast, there were no measurable changes following exposure to the static field, or to the oscillating field alone, and the authors have suggested a frequency/intensity specific cyclotron resonance mechanism for the effect, as well as a range of bioeffects, mostly involving alterations in membrane calcium ion flux. Lovely *et al.* (1992a; 1992b), reasoning that it is the movement of calcium ions which is influenced by the interaction of the ELF and geomagnetic fields, and so causing behavioral effects, also used a combination of horizontal AC and DC fields (0.5 and 0.26 G, respectively). Rats always exposed to this field showed significantly higher error rates than sham exposed rats in spatial learning and memory in a radial arm maze, while those exposed half the time exhibited intermediate error rates. The task difficulty was so minimal, however, that pretraining prevented any memory deficits. Wilson (1990)(Wilson 1991) has also produced some evidence that magnetic fields (3 coils at 60 Hz and a central coil to produce a vertical DC field), set up for calcium ion cyclotron resonance, can interfere with maze-running performance by rats through an effect on short-term memory. A recent attempt to replicate this experiment (with minor variations) was not successful (Creim *et al.* 1993).

A final element that might be relevant to behavioral effects, is the action of EMFs on the neurohumoral system. Luben *et al.* (1991) has shown that low energy EMF, pulsed at 15 Hz but not at 72 Hz, inhibited the beta-adrenergic action of mouse bone cells. EMF also decreased signal transduction by the parathyroid hormone receptor by as much as 90%, through a mechanism apparently involving interaction with membrane G proteins (Luben 1992). Mouse bone marrow cells exposed to a 1 G, 60 Hz magnetic field also showed modulation of various enzymes in signal transduction pathways regulating growth, including protein kinase C (Nguyen and others 1992) and membrane G proteins responding to parathyroid hormone and isoproterenol receptors (Luben and others 1992). While the cells involved are not of neural origin, the effect might be of wider significance, since other members of the G protein receptor family (adrenergic, muscarinic, serotoninergic and peptidergic) might also be susceptible to EMF. More directly related to the nervous system, Ossenkopp and Kavaliers (1989) reviewed the evidence that low frequency magnetic fields (0.5 Hz, 1.5-90 G) modulated significantly the activity of endogenous or exogenous opiates in mice, with respect both to their analgesic and locomotory actions. The authors concluded that mu, kappa, and delta, but not sigma receptors, were affected by the magnetic field. In rats exposed to a 50 Hz, 58 G magnetic field for up to 28 days, levels of bioamines in the striatum of the brain were altered, with reductions in dopamine and serotonin levels after 28 days, and increases, beginning at 7 days for homovanillic and 3,4-dihydroxyphenylacetic acids, and at 21 days for 5-hydroxyindole-acetic acid (Zecca *et al.* 1989). A report from China has also claimed that 50 Hz electric fields produce changes in bioamine neurochemistry (Yao *et al.* 1992). In this study groups of male Wistar rats were sham exposed, or exposed for 5 h/day for 66 days to fields of 4 or 40 kV/m and levels of amines determined in the hippocampus and hypothalamus. Whereas in the hippocampus, levels of both catecholamine and serotonin were reduced in the exposed groups, in the hypothalamus, only catecholamine showed a significant reduction.

7.6 STUDIES OF HIGH-STRENGTH STATIC MAGNETIC FIELDS

Behavioral effects of high intensity static magnetic field exposure have been documented in a number of animal studies. deLorge (1978) reviewed some of the early work with non-human primates in high static magnetic fields. In one study three squirrel monkeys (*Saimiri sciureus*) were conditioned to respond on a visual vigilance task and were subsequently exposed to a direct current magnetic field in the core of a water-cooled Bitter magnet. Response was greatly suppressed by fields of 70 kG or more and a threshold seemed to exist between 46 and 70 kG. A second experiment in a superconducting magnet in which eight squirrel monkeys were trained on several operant tasks revealed similar suppressive effects at magnetic field strengths of up to 97 kG. In addition, two of the monkeys regurgitated when exposed to the higher fields. All of these effects were reproducible. Studies using rhesus (*Macaca mulatta*) and squirrel monkeys revealed no behavioral effects of extremely-low-frequency electromagnetic fields at lower intensities (magnetic fields ranging from 3-10 G and electric fields from 1-29 V/m rms at frequencies of 7, 10, 15, 45, 60, and 75 Hz). No consistent effects other than one unreplicated effect on general activity, were observed.

Chronic exposure of rats to a static horizontal 6 kG magnetic field during the last few weeks of conditioning inhibited the performance of avoidance responses, and behavioral carryover of this effect of exposure during learning, occurred in a manner similar to effects of stressful physical stimuli such as loud noise and low temperature (Nakagawa and Matsuda 1988). Conditioned rats exposed after 15 weeks of training showed only slightly increased lever-pressing frequency during the exposure week, indicating that the effect of the exposure was not strong enough to affect a well conditioned response in rats. This latter finding is reminiscent of that reported by Lovely *et al.* (1992a) for low strength fields, which was described in Section 7.5.

More recent studies have addressed the problem of the effects of magnetic fields of the type generated by MRI. Since some features of such fields may resemble components of those generated by some proposed maglev systems, these experiments are of interest and will be reviewed in more detail. In some cases, animal studies have been conducted which involve exposure to just the static magnetic field component of magnetic resonance imaging (MRI), but in most experiments, animals were exposed to some combination of time-varying magnetic and radiofrequency fields characteristic of MRI devices, or to the clinical devices themselves. Concern exists that MRI fields may alter the permeability of the blood-brain barrier (BBB), and results of experiments to evaluate this possibility have produced contradictory results. For example, Ross *et al.* (1990) reported no effect of MRI conditions on the permeation of ^{125}I-labelled bovine serum albumin through the BBB of rats, while Preston and coworkers (1989) found no effect on permeation by [^{14}C]sucrose. However, Prato *et al.* (1990) found that rats injected intracardially with radio-labelled diethylenetriaminepentaacetic acid ([^{153}Gd]DTPA, a chelate which has low BBB permeability) between two sequential 23.2 min MRI exposures, showed significantly greater (29%, p=0.006) brain retention of [^{153}Gd]DTPA than did sham exposed rats (n=22) 1 h after the end of the last 23.2-min exposure. In subsequent work, this same group showed that these effects on BBB permeability occurred after exposure to low-field (1.5 kG), but not high-field (15 kG) MRI (Prato *et al.* 1992). Ravnborg *et al.* (1990) assessed the effects of a transcranial magnetic pulse with 163 μsecond rise time, a 4 ms decay, and a peak intensity of 19 kG in anesthetized rats, and found no effect on BBB permeability.

Chuvpilo (1982) noted differences in the levels of sodium fluorescein in several brain regions following exposure of anesthetized rats to a constant 4 kG magnetic field for 3 h. Garber *et al.* (1989) followed tritiated mannitol permeation in groups of adult male rats exposed to MRI procedures at 15, 5 and 3 kG. Increased brain mannitol associated with gradient fields may reflect increased blood-brain barrier permeability or brain blood volume. Brain mannitol concentration was significantly increased at 3 and 5 kG but not at 15 kG. At 3 kG, exposure to the type of gradient field fluctuations used for imaging increased brain mannitol concentration, while exposures to the static main field and pulsed radiofrequency energies did not. These findings of an effect at lower field strength recall those of Prato's group, discussed above. Persson *et al.* (1991) found an increase in the extravasation of Evans Blue and albumin with all components of the MRI fields, but the strongest effect was obtained with pulsed 915 MHz microwaves at 215, 50, 16, and 8 Hz modulation frequency. These results suggest that pulsed electromagnetic fields have greater potency to open the blood brain barrier. At the present time it is not possible to determine if these differences in experimental results are due to differences in experimental methodology, or in the type of EMF exposure. Questions have been raised regarding possible effects of anesthetics, imperfect temperature control, stress, or artifacts associated with tracers like Evans Blue.

8. ANIMAL AND CELLULAR STUDIES ON "WINDOW" EMF EFFECTS

One of the most interesting claims made in the literature is the existence of what have been termed window effects; bioeffects of EMF occurring only at particular combinations of frequency, field strength and, in many cases, polarity of the ELF EMF field with respect to the earth's static magnetic field. The experiments that have demonstrated window effects will not be described in detail in this report, but it is appropriate to review them in brief, since ultimately such window effects, if proven, could be critical to defining the characteristics of EMF that might present possible health hazards, and to making decisions regarding risk mitigation.

For the most part, demonstrations of a window effect have emerged from the initial studies of ion transport carried out by Adey, Bawin and coworkers (Adey *et al.* 1982; Adey and Bawin 1982; Bawin *et al.* 1984) as extended by others (Blackman 1989; Adey 1989; Liboff *et al.* 1989; Leal *et al.* 1989). Calcium flux, measured directly or indirectly through such phenomena as diatom motility, also operates with frequency/intensity specificity in several biological systems (Liboff *et al.* 1989). Reports of signal-specific quantitative and qualitative differences in the transcriptional response to EMF in several different tissues (Goodman and Henderson 1987) may reflect another aspect of this phenomenon. Collectively, these observations suggest that ELF EMF effects may depend to a large extent on the "informational" content of the EMF signal being transferred to biological systems through some type of resonance coupling, rather than by simple deposition of net energy. Similar theoretical arguments for frequency specificity have been advanced by Weaver and Astumian (1989) and by Tsong and Markin (1992) to explain how bioeffects could be produced by ELF EMF at energy levels below that of thermal noise.

The clearest response associated with specific frequency/intensity EMF stimuli is a change in calcium flux through the cell membrane; the evidence for this has been reviewed (Creasey and Goldberg 1989). Calcium plays a vital role in various electrophysiological processes such as cardiac and skeletal muscle contractility. Intracellular calcium levels and calcium fluxes are also implicated, through signal transduction mechanisms, in the control of normal cell functions, including growth and division (Hesketh *et al.* 1987; Whitfield *et al.* 1985; Rozengurtz and Mendoza 1986). EMF effects on calcium flux have been particularly well studied in the chicken brain *in vitro*. Blackman (Blackman 1989; Blackman *et al.* 1990) found that specific EMF frequencies in the ELF range were required to enhance calcium efflux. Other systems in which EMF has modulated calcium flux include single cells (fibroblasts, lymphocytes, neuroblastoma cells, diatoms (Liboff *et al.* 1989; Emilia *et al.* 1985; Liburdy *et al.* 1988), microsomal membranes (Stagg *et al.* 1992) and isolated sarcoplasmic reticulum (Surgalla 1988). Static and time-varying field combinations produced by an MRI device also have been reported to increase cytosolic free calcium in undifferentiated HL-60 cells (Carson *et al.* 1990). In the cell line TALL-1, a DC magnetic field with a flux density of 4 kG significantly increased the efflux rate of Adriamycin by about 5% in field-exposed cells at 42 and 44 C, an effect which was ascribed to a change in conformation of membrane molecular structure (Aoki *et al.* 1990).

Not all of these studies employed powerline-frequency EMF. Some employed the complex fields used in MRI, while in most, higher frequency (e.g., radiofrequency) EMF, amplitude-modulated or intermittently-generated (pulsed) at ELF provided the test exposures. These fields are considered in the context of ELF EMF effects since it appears that the modulation frequency rather than the carrier wave frequency is the critical feature for biological interactions. This has implications for maglev trains which generate a complex pattern of ELF and pulsed EMF that also would be associated with high-strength magnetic fields.

The sheer variety of cellular systems that are affected by intracellular calcium fluxes makes it difficult to ascribe specific results to such interactions. Even within one experimental system the effects can vary, as for example with lymphocyte mitogenesis, where one set of EMF frequency/intensity characteristics can stimulate while another set can be inhibitory (Franceschi *et al.* 1986; Cadossi *et al.* 1986). Modulation of ion fluxes and changes in cell communication are processes that might both spring from a common biophysical mechanism such as voltage-gated membrane channel effects of the type discussed by Blank (1987), or magnetic deformation of phospholipid domain structures normally existing at pretransition-phase temperatures (Tenforde and Liburdy 1988).

A theoretical basis for window effects and the interaction of geomagnetic (DC) and time-varying magnetic fields as a form of ion cyclotron resonance has been advocated by Liboff *et al.* (1989). An alternative mechanism to explain the same results, described as "parametric" resonance, has been proposed by Lednev (1991, 1992). Tsong and Markin (1992) have formulated the concept of an oscillatory activation barrier for cellular transduction of EMF signals that includes frequency windows and amplitude saturation effects. Such theories provide a unifying physical mechanism to account for a range of low-level ELF EMF effects in different biological systems, and provide an explanation of why effects appear only under specific conditions of frequency and intensity. Each theory makes certain predictions of "active" frequency/intensity windows which are currently being tested in experimental systems.

9. EMF GUIDELINES

The gist of much of this report has been that there is currently inadequate knowledge, both of the detailed features of the magnetic fields generated by potential new electric transportation systems, and of which characteristics of such fields might be harmful biologically. Therefore, official organizations and governmental agencies have no logical basis on which to arrive at acceptable guidelines or recommendations covering exposure to ELF EMF. Nevertheless, public pressure has been exerted to regulate exposures. This pressure has resulted in part from media publicity regarding specific studies reporting adverse effects of EMF, and also from inadequate awareness among the public of the relative importance of the multiple personal and environmental health risks to which the population is exposed (Valberg 1992; Delpizzo and Elliott 1992). In the absence of definitive knowledge, the few regulatory guidelines that exist have been based on such factors as estimates of the time-averaged intensities of existing EMF emissions (for which data is frequently patchy); extrapolation from requirements set up for high field devices such as MRI equipment; estimates of induced electric currents in tissues; and the concept of "prudent avoidance," a term with varying interpretations (Hersh and Pura 1992).

Table 9-1 presents a brief overview of the major existing recommendations and guidelines as they relate to time-varying magnetic fields. It should be noted that the intensities of the fields generated by the prototype TR07 maglev fall well within these guidelines, with the possible exception of the Florida State guideline, which is based on existing field levels rather than health effects. However, with the exception of minor variations for frequency and occupational peak exposure, they do not attempt to address either the complex nature of the emissions that current surveys are revealing, or the question of window effects.

TABLE 9-1. NATIONAL AND INTERNATIONAL GUIDELINES AND RECOMMENDATIONS WITH RESPECT TO TIME-VARYING MAGNETIC FIELDS

Official Body or Country	Reference	Guidelines
American Conference of Governmental Hygienists (ACGIH)	1990-1991 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices, Third Printing	10 G at 60 Hz 24 G at 25 Hz (Threshold Limit Value)
Florida and New York States	Electric and Magnetic Fields, Chapter 17-274, Florida Administrative Code Statement of Interim Policy on Magnetic Fields of Major Electric Transmission Facilities, State of New York Public Service Commission, September 11, 1990	150-250 mG at transmission line boundaries depending on type of transmission line
International Radiation Protection Association	Interim Guidelines on Limits of Exposure to 50/60 Hz Electric and Magnetic Fields. Health Physics 58:113-22, 1990	For general public: 1 G at 24 h/day; up to 10 G for a few h/day For occupational exposures: 5 times that for the general public
Germany	Safety of Electromagnetic Fields; Limits of Field Strengths for the Protection of Persons in the Frequency Range from 0 to 30 kHz, DIN VDE 0848 Part 4, VDE VERLAG GMBH, D-1000 Berlin, October 12, 1989	Frequency-dependent for 2 Hz to 30 kHz with relationship: $B_{RMS} = 270/f^{0.4324}$ This gives limit of 50 G at 50 Hz; 50% greater allowance for intermittent or peak exposure
United Kingdom	National Radiological Protection Board (NRPB-GS11, 1989) Chadwick, P.J., *First World Congress for Electricity and Magnetism in Biology and Medicine*, June, 1992	20 G below 100 Hz, NRPB proposed 1992 guidelines: 4 G at 50 Hz 8 G at 100 Hz
World Health Organization	World Health Organization, 1987, Environmental Health Criteria 69: Magnetic Fields. Geneva: World Health Organization	10 mA/m² tissue current density, equivalent to approximately 10 G at powerline frequency

10. CONCLUSIONS

This report has outlined the research on the biological and health effects of EMF that is most relevant to the fields generated by maglev and other high-speed electric transportation systems. A number of conclusions can be made:

- It is premature to attempt to specify the types of low-intensity fields likely to be associated with adverse health effects until the exposures involved in the epidemiologic findings have been fully documented, and causal links to bioeffects convincingly demonstrated. Epidemiologic results suggest a probable low-level health risk associated with ELF EMF (at or near powerline frequency), and specifically with the magnetic component of such fields. Until it is experimentally confirmed, however, a causal association between magnetic fields and these health effects remains speculative;

- Experimental evidence suggests that there are window effects at specific frequencies for bioeffects which may or may not relate to health effects. Other experimental results also suggest that a linear dose-response relationship (with respect to magnetic field intensity) is not operative for many bioeffects: responses seem to occur over a threshold level, with no further increase in response at higher intensities. If such results can be generalized to bioeffects involved in health risks, it suggests that frequency/intensity characteristics of an exposure may be an important consideration in evaluating risks of new technology;

- High strength magnetic fields (in or near the kilogauss range as used in MRI) may present specific problems for those with metallic implants, pacemakers, etc.;

- For purposes of exposure assessment in health effects studies, it is important to differentiate between field exposures in different countries, at different times, and for various occupational categories. For example, at the present time, it is not known if 50 and 60 Hz fundamental frequencies produce different effects, or if rapidly changing fields produced by mechanical relays act differently from more slowly changing fields, as some studies have suggested. Similarly, it is important to document the EMF environment of current and prototype rail systems in sufficient detail to be aware of differences and similarities in field characteristics of various national and international systems. Finally, occupational categories used as the basis for epidemiologic studies need to be better defined in terms of the characteristics of frequency, variability, duration, and intensity of EMF exposure that they entail, perhaps through extensive EMDEX surveys;

- Even if more detailed information were available about fields produced by maglev and other high-speed transportation, it still would not be possible to describe specific fields as being more or less hazardous, because of the paucity of field-specific, dose-response information on health effects in the literature. However, it is important to collect data on specific field characteristics for two reasons: (a) to facilitate legalistic comparisons to indicate in what ways maglev exposures resemble or differ from other types of exposure; and, (b) if future research defines field characteristics associated with a significant biological effect, it will then be possible to quickly conclude whether the effect is or is not relevant to maglev exposures;

- The general level of risk associated with ELF EMF at powerline frequencies is, at the present time, the most relevant risk to ascribe to maglev systems (there is no *a priori* reason to consider them a greater or lesser risk). This level of risk is at most small, in the case of cancer, for example, the relative risk is about 1.3, but this estimate currently rests almost entirely on epidemiologic data;

- Of the effects that have been ascribed to EMF, those supported by the most convincing evidence are altered circadian rhythms of melatonin secretion, modulation of transmembrane calcium transport, slight increases in the relative risks for some rare cancers, and some mild behavioral disturbances;

- If experimental work is done to assess the potential health effects of maglev fields, general screening experiments (for example, by exposing an animal colony to maglev fields and looking for any acute or long-term effects) are less likely to be productive than experiments which build on work already done with powerline frequency ELF EMF. Negative results in a general screening experiment may not necessarily differentiate between an inactive field and an assay system that lacks sensitivity, leaving the human health effects question open. Positive results may be the result of a chance observation if a great many endpoints are screened looking for any possible effect; extensive additional work may be required to resolve such an initial positive observation. Direct comparison with an assay system known to respond to 60 Hz fields allows an answer to the question "are maglev fields more or less biologically active than power frequency fields?"

- Work is currently in progress both to improve the assay systems that have shown a replicated response to 60 Hz fields by identifying uncontrolled variables, and to establish reproducible methodology that can be used in any laboratory. There is also a need to develop new, more reliable animal models, in which it is possible to use EMF with defined characteristics in order to establish just what features present biologic hazards. DOT should build on this work by testing various maglev fields (when they are defined by more complete measurements) in the best of these systems.

11. REFERENCES

Adey, W. R. 1989. ELECTROMAGNETIC FIELDS, CELL MEMBRANE AMPLIFICATION, AND CANCER PROMOTION. Extremely Low Frequency Electromagnetic Fields: The Question of Cancer. B. W. Wilson, R. G. Stevens, L. E. Anderson, eds., Columbus, OH: Battelle Press, p. 211-249

Adey, W. R., and S. M. Bawin. 1979. BRAIN INTERACTIONS WITH WEAK ELECTRIC AND MAGNETIC FIELDS. Neurosci Res Program Bull 15(1):7-129

Adey, W. R., and S. M. Bawin. 1982. BINDING AND RELEASE OF BRAIN CALCIUM BY LOW-LEVEL ELECTROMAGNETIC FIELDS: A REVIEW. Radio Sci 17(5S):149S-157S

Adey, W. R., S. M. Bawin, and A. F. Lawrence. 1982. EFFECTS OF WEAK AMPLITUDE-MODULATED MICROWAVE FIELDS ON CALCIUM EFFLUX FROM CAT CEREBRAL CORTEX. Bioelectromagnetics 3(3):295-307

Adolphe, M., V. Friese, R. Portet, and J. Cabanes. 1987. EFFECT OF A LOW-INTENSITY MAGNETIC FIELD ON THE PROLIFERATION OF SEVERAL LINES OF CULTURED CELLS. C R Soc Biol (Paris) 181(3): 282-286

Ahlbom, A. 1988. A REVIEW OF THE EPIDEMIOLOGIC LITERATURE ON MAGNETIC FIELDS AND CANCER. Scand J Work Environ Health 14(6):337-343

Aldrich, T. E., and C. E. Easterly. 1987. ELECTROMAGNETIC FIELDS AND PUBLIC HEALTH. Environ Health Perspect 75:159-171

Aoki, H., H. Yamazaki, T. Yoshino, and T. Akagi. 1990. EFFECTS OF STATIC MAGNETIC FIELDS ON MEMBRANE PERMEABILITY OF A CULTURED CELL LINE. Res Commun Chem Pathol Pharmacol 69(1):103-106

Armanini, D., R. Conti, A. Mantini, P. Nicolini, F. Di Lecce, F. Lattarulo, and G. Mastronardi. 1989. ENEL'S EXPERIENCE IN THE AREA OF POWER-FREQUENCY ELECTROMAGNETIC FIELD MEASURING TECHNIQUES: PROBLEMS RELATED TO DESIGN, CALIBRATION, AND USE OF MEASURING DEVICES. Alta Frequenza 58(4):403-410

Arnetz, B. B., M. Berg, and S. Liden. 1992. JOB STRESS AND "HYPERSENSITIVITY TO ELECTRICITY" (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p.77

Asanova, T. P., and A. N. Rakov. 1966. THE HEALTH STATUS OF PEOPLE WORKING IN THE ELECTRIC FIELD OF OPEN 400-500 KV SWITCHING STRUCTURES. Gig Tr Prof Zabol 10(5):50-52

Athey, T. W. 1990. FDA SAFETY GUIDANCE FOR MAGNETIC RESONANCE DEVICES (MEETING ABSTRACT). Bioelectromagnetics Society, 12th Annual Meeting, 10-14 June, San Antonio, TX, p. 43

Balli-Antunes, M., D. H. Pfluger, and Ch. E. Minder. 1990. THE MORTALITY FROM MALIGNANCIES OF HAEMATOPOIETIC AND LYMPHATIC SYSTEMS (MHLS) AMONG RAILWAY ENGINE DRIVERS. IS EXPOSURE TO LOW FREQUENCY ELECTROMAGNETIC FIELDS ASSOCIATED WITH AN INCREASE OF MORTALITY FROM MHLS ? Environmetrics 1(1):121-130

Baroncelli, P., S. Battisti, A. Checcucci, P. Comba, M. Grandolfo, A. Serio, and P. Vecchia. 1986. A HEALTH EXAMINATION OF RAILWAY HIGH-VOLTAGE SUBSTATION WORKERS EXPOSED TO ELF ELECTROMAGNETIC FIELDS. Am J Ind Med 10(1):45-55

Bawin, S. M., A. R. Sheppard, M. D. Mahoney, and W. R. Adey. 1984. INFLUENCES OF SINUSOIDAL ELECTRIC FIELDS ON EXCITABILITY IN THE RAT HIPPOCAMPAL SLICE. Brain Res 323(2):227-237

Bellossi, A., I. Bernard-Griffiths, and M. Le Gall. 1988. EFFECT OF ELF PULSED MAGNETIC FIELDS ON SURVIVAL OF LEUKEMIA-PRONE AKR MICE. In Vivo 2(5):335-338

Berman, E., L. Chacon, D. House, B. A. Koch, W. E. Koch, J. Leal, S. Lovtrup, E. Mantiply, A. H. Martin, G. I. Martucci, K. H. Mild, J. C. Monahan, M. Sandstrom, K. Shamsaifar, R. Tell, M. A. Trillo, A. Ubeda, and P. Wagner. 1990. DEVELOPMENT OF CHICKEN EMBRYOS IN A PULSED MAGNETIC FIELD. Bioelectromagnetics 11(2):169-187

Bersani, F., C. Franceschi, D. Monti, A. Cossarizza, R. Cadossi, M. R. Scarfi, G. Castellani, P. Conti, M. Reale, and G. E. Gigante. 1992. LYMPHOCYTE PROLIFERATION AFTER EXPOSURE TO TWO DIFFERENT KINDS OF PULSED MAGNETIC FIELDS: INTERCOMPARISON BETWEEN TWO DIFFERENT LABS (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 58

Blackinton, D., M. Lefebvre, D. Cherlin, C. Polk, and S. Mehta. 1992. ACCELERATED HUMAN LYMPHOCYTE GROWTH IN A 1 GAUSS, 15 HZ MAGNETIC FIELD (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 58

Blackman, C. F. 1989. ELF EFFECTS ON CALCIUM HOMEOSTASIS. Extremely Low Frequency Electromagnetic Fields: The Question of Cancer. B. W. Wilson, R. G. Stevens, L. E. Anderson, eds., Columbus, OH: Battelle Press, p. 187-208

Blackman, C. F., S. G. Benane, D. E. House, and D. J. Elliott. 1990. IMPORTANCE OF ALIGNMENT BETWEEN LOCAL DC MAGNETIC FIELD AND AN OSCILLATING MAGNETIC FIELD IN RESPONSES OF BRAIN TISSUE IN VITRO AND IN VIVO. Bioelectromagnetics 11(2):159-167

Blank, M. 1987. ION CHANNELS IN EXCITABLE MEMBRANES AS SHORT CIRCUITS BETWEEN ELECTRICAL DOUBLE LAYERS. J Electrochem Soc 134(2):343-346

Blask, D. E. 1989. THE EMERGING ROLE OF THE PINEAL GLAND AND MELATONIN IN ONCOGENESIS. Extremely Low Frequency Electromagnetic Fields: The Question of Cancer. B. W. Wilson, R. G. Stevens, L. E. Anderson, eds., Columbus, OH: Battelle Press, p. 319-335

Bornhausen, M. 1989. EXPOSURE OF PREGNANT RATS TO A 10 TESLA STATIC MAGNETIC FIELD: OPERANT BEHAVIOR CONSEQUENCES IN OFFSPRING (MEETING ABSTRACT). Bioelectromagnetics Society, 11th Annual Meeting, 18-22 June, Tucson, AZ, p. 39

Bowman, J. D., D. H. Garabrant, E. Sobel, and J. M. Peters. 1988. EXPOSURES TO EXTREMELY LOW FREQUENCY (ELF) ELECTROMAGNETIC FIELDS IN OCCUPATIONS WITH ELEVATED LEUKEMIA RATES. Appl Ind Hyg 3(6):189-194

Bowman, J. D., and C. A. Kardous. 1991. CHARACTERISTICS OF STATIC AND ELF MAGNETIC FIELDS FROM OCCUPATIONAL SOURCES (MEETING ABSTRACT). Annual Review of Research on Biological Effects of 50 and 60 Hz Electric and Magnetic Fields, 3-7 November 1991, Milwaukee, WI, U.S. Dept. of Energy, p. P-4

Bowman, J. D., E. Sobel, J. M. Peters, and S. J. London. 1989. ASSESSMENT OF MAGNETIC AND ELECTRIC FIELD EXPOSURES BY JOB CATEGORY (MEETING ABSTRACT). Annual Review of Research on Biological Effects of 50 and 60 Hz Electric and Magnetic Fields, 13-16 November 1989, Portland, OR, U.S. Dept. of Energy, p. A-41

Bowman, J. D., D. C. Thomas, and J. M. Peters. 1991. THE RISK OF CHILDHOOD LEUKEMIA FROM HOME EXPOSURE TO RESONANCES FROM STATIC AND POWER-FREQUENCY MAGNETIC FIELDS (MEETING ABSTRACT). Annual Review of Research on Biological Effects of 50 and 60 Hz Electric and Magnetic Fields, 3-7 November 1991, Milwaukee, WI, U.S. Dept. of Energy, p. A-40

Bracken, T. D., R. F. Rankin, J. R. Alldredge, and R. S. Senior. 1990. ELECTRIC AND MAGNETIC FIELD MEASUREMENT PROJECT FOR UTILITIES -- THE EMDEX PROJECT (MEETING ABSTRACT). Bioelectromagnetics Society, 12th Annual Meeting, 10-14 June, San Antonio, TX, p. 13

Brinkmann, K., S. Buntenkotter, E. Zittlau, R. Zwingelberg, and H. J. Reinhard. 1988. A TERATOLOGICAL STUDY ON RATS EXPOSED TO 50 Hz MAGNETIC FIELDS (MEETING ABSTRACT). Bioelectromagnetics Society, 10th Annual Meeting, 19-24 June, Stamford, CT, p. 38

Brown, H. D., and S. K. Chattopadhyay. 1988. ELECTROMAGNETIC-FIELD EXPOSURE AND CANCER. Cancer Biochem Biophys 9(4):295-342

Browne, M. W. 1992. NEW FUNDS FUEL EFFORTS TO DEVISE MAGNET POWER FOR TRAINS. The New York Times, March 3, 1992, p. C1, C11

Budd, R. A., and P. Czerski. 1985. MODULATION OF MAMMALIAN IMMUNITY BY ELECTROMAGNETIC RADIATION. J Microw Power 20(4):217-231

Buntenkotter, S., K. Brinkmann, E. Zittlau, R. Zwingelberg, H-J. Reinhard, and M. Mevissen. 1990. AN ONCOLOGICAL STUDY WITH DMBA+ ON RATS EXPOSED TO 50 HZ MAGNETIC FIELDS (MEETING ABSTRACT). Bioelectromagnetics Society, 12th Annual Meeting, 10-14 June, San Antonio, TX, p. 16

Butrous, G. S. C., R. S. Bexton, D. G. Barton, J. Male, and A. J. Camm. 1983. INTERFERENCE WITH THE PACEMAKERS OF TWO WORKERS AT ELECTRICITY SUBSTATIONS. Br J Ind Med 40(4):462-465

Cadossi, R., G. Ceccherelli, G. Emilia, and G. M. Torelli. 1986. EFFECT OF ELF ELECTROMAGNETIC FIELDS ON LECTIN INDUCED LYMPHOCYTE PROLIFERATION (MEETING ABSTRACT). Bioelectromagnetics Society, 8th Annual Meeting, 1-5 June 1986, Madison, WI, p. 30

Calle, E. E., and D. A. Savitz. 1985. LEUKEMIA IN OCCUPATIONAL GROUPS WITH PRESUMED EXPOSURE TO ELECTRICAL AND MAGNETIC FIELDS [LETTER]. N Engl J Med 313(23):1476-1477

Cantini, M., A. Cossarizza, F. Bersani, R. Cadossi, G. Ceccherelli, R. Tenconi, C. Gatti, and C. Franceschi. 1986. ENHANCING EFFECT OF LOW FREQUENCY PULSED ELECTROMAGNETIC FIELDS ON LECTIN-INDUCED HUMAN LYMPHOCYTE PROLIFERATION. J Bioelectr 5(1):91-104

Carson, J. J., F. S. Prato, D. J. Drost, L. D. Diesbourg, and S. J. Dixon. 1990. TIME-VARYING MAGNETIC FIELDS INCREASE CYTOSOLIC FREE CA2+ IN HL-60 CELLS. Am J Physiol 259(4 Pt 1):C687-C692

Casamento, J., B. Crowl, and H. Bassen. 1992. SPATIALLY MAPPED MAGNETIC AND ELECTRIC FIELDS FROM ELECTRIC BLANKETS (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 75

Chacon, L., M. A. Martinez, V. Madurga, A. Nunez, A. Ubeda, M. A. Trillo, M. L. Tejera, and J. Leal. 1989. RESPONSE OF EARLY EMBRYOS TO A COMBINATION OF WEAK DC AND AC MAGNETIC FIELDS DETERMINED TO PRODUCE CYCLOTRONIC RESONANCE OF CALCIUM IONS (MEETING ABSTRACT). Bioelectromagnetics Society, 11th Annual Meeting, 18-22 June, Tucson, AZ, p. 61-62

Chacon, L., M. A. Trillo, A. Ubeda, M. A. Martinez, and J. Leal. 1992. EFFECTS OF MAGNETIC FIELDS AT CYCLOTRON RESONANCE CONDITIONS ON THE EARLY CHICK EMBRYO (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 15-16

Chadwick, P. J., and F. I. Lowes. 1992. MAGNETIC FIELDS FROM TRANSPORT SYSTEMS IN THE UK (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 67

Chartier, V. L., L. D. Dickson, and R. D. Stearns. 1991. JOINT HVAC TRANSMISSION EMF ENVIRONMENTAL STUDY: ELECTRICAL MONITORING (MEETING ABSTRACT). Annual Review of Research on Biological Effects of 50 and 60 Hz Electric and Magnetic Fields, 3-7 November 1991, Milwaukee, WI, U.S. Dept. of Energy, p. P-6

Chuvpilo, T. A. 1982. PERMEABILITY OF THE BLOOD-BRAIN-BARRIER DURING EXPOSURE TO A CONSTANT-MAGNETIC-FIELD (MEETING ABSTRACT). All-Union Symposium on the Biological Effects of Electromagnetic Fields, Pushchino, USSR, p. 81-82

Coelho, A. M., Jr., S. P. Easley, and W. R. Rogers. 1991a. EFFECTS OF EXPOSURE TO 30 KV/M, 60 Hz ELECTRIC FIELDS ON THE SOCIAL BEHAVIOR OF BABOONS. Bioelectromagnetics 12(2):117-135

Coelho, A. M., Jr., S. P. Easley, and W. R. Rogers. 1991b. EVALUATING THE EFFECTS OF 60 Hz COMBINED (6 KV/M AND 50 uT) ELECTRIC AND MAGNETIC FIELDS ON BABOON SOCIAL BEHAVIOR (MEETING ABSTRACT). Bioelectromagnetics Society, 13th Annual Meeting, 23-27 June, Salt Lake City, UT, p. 33

Coleman, M., and J. Bell. 1987. LEUKAEMIA AND RESIDENCE NEAR ELECTRICITY TRANSMISSION EQUIPMENT: A CASE-CONTROL STUDY (MEETING ABSTRACT). Biological Effects From Electric and Magnetic Fields, Air Ions and Ion Currents Associated with High Voltage Transmission Lines: Contractors Review. 1-4 November 1987, Kansas City, MO. U.S. Dept. of Energy, Office of Energy Storage and Distribution, Washington, D.C., and Electric Power Res. Inst., Health Studies Program, Palo Alto, CA.

Coleman, M., J. Bell, and R. Skeet. 1983. LEUKAEMIA INCIDENCE IN ELECTRICAL WORKERS (LETTER). Lancet 1(8331):982-983

Coleman, M., and V. Beral. 1988. A REVIEW OF EPIDEMIOLOGICAL STUDIES OF THE HEALTH EFFECTS OF LIVING NEAR OR WORKING WITH ELECTRICITY GENERATION AND TRANSMISSION EQUIPMENT. Int J Epidemiol 17(1):1-13

Coleman, M. P., C. M. J. Bell, H-L. Taylor, and M. Primic-Zakelj. 1989. LEUKEMIA AND RESIDENCE NEAR ELECTRICITY TRANSMISSION EQUIPMENT: A CASE-CONTROL STUDY. Br J Cancer 60(5): 793-798

Conti, P., G. E. Gigante, M. G. Cifone, E. Alesse, C. Fieschi, and P. U. Angeletti. 1985. EFFECT OF ELECTROMAGNETIC FIELDS ON TWO CALCIUM DEPENDENT BIOLOGICAL SYSTEMS. J Bioelectr 4(1):227-236

Conti, P., G. E. Gigante, M. G. Cifone, E. Alesse, G. Ianni, M. Reale, and P. U. Angeletti. 1983. REDUCED MITOGENIC STIMULATION OF HUMAN LYMPHOCYTES BY EXTREMELY-LOW-FREQUENCY ELECTROMAGNETIC-FIELDS. FEBS Lett 162(1):156-160

Cossarizza, A., D. Monti, M. Capri, S. Saivioli, R. Cadossi, M. R. Scarfi, G. Gottardi, F. Bersani, and C. Franceschi. 1992. EFFECTS OF DIFFERENT ELECTROMAGNETIC SIGNALS ON HUMAN LYMPHOCYTE PROLIFERATION INDUCED BY DIFFERENT MITOGENS (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 58

Cossarizza, A., D. Monti, C. Franceschi, B. Darnell, and W. D. Winters. 1989. HUMAN NK AND LAK ACTIVITY AFTER EXPOSURE TO DIFFERENT LOW FREQUENCY ELECTROMAGNETIC FIELDS (MEETING ABSTRACT). J Bioelectr 8(2):328 International Symposium in Honor of Luigi Galvani, 14-16, April, Bologna, Italy

Creasey, W. A., and R. B. Goldberg. 1989. EXTREMELY LOW FREQUENCY ELECTRIC AND MAGNETIC FIELDS AND CANCER: A LITERATURE REVIEW. Electric Power Research Inst., Palo Alto, CA, Research Project 2965-12, Final Report, December 1989, Publication EN-6674; 125 pp.

Creim, J., R. H. Lovely, D. L. Miller, B. W. Wilson, and L. E. Anderson. 1993. FAILURE TO GENERALIZE PERFORMANCE DECREMENTS IN A RADIAL ARM MAZE IN RATS EXPOSED TO A 0.5 G, 60 Hz PULSED MAGNETIC FIELD (MEETING ABSTRACT). Bioelectromagnetics Society, 15th Annual Meeting, 13-17 June, Los Angeles, CA, p. 156-157

Cresswell, L. A., and C. K. Gowers. 1989. SHIELDING AGAINST EXTRA-LOW-FREQUENCY (ELF) MAGNETIC FIELDS. Electric Energy Conference 1989, 24-26 October, Sydney, Australia, pp. 13-15

Cummings, D. O., and D. C. Robertson. 1990. PRELIMINARY RESULTS OF MAGNETIC FLUX DENSITY MEASUREMENTS ON TR07 VEHICLE AND MAGLEV SYSTEM AT EMSLAND, FRG, 6-10 AUGUST 1990 (MEETING ABSTRACT). Annual Review of Research on Biological Effects of 50 and 60 Hz Electric and Magnetic Fields, 5-8 November 1990, Denver, CO, U.S. Dept. of Energy, p. A12

Czerski, P. 1988. EXTREMELY LOW FREQUENCY (ELF) ELECTRIC FIELDS: BIOLOGICAL EFFECTS AND HEALTH RISK ASSESSMENT. Non-ionizing Radiations: Physical Characteristics, Biological Effects and Health Hazard Assessment. Proceedings of the International Non-Ionizing Radiation Workshop, 5-9 April 1988, Melbourne, Australia, M. H. Repacholi, ed., London: International Radiation Protection Association Publications, p. 255-271

De Guire, L., G. Theriault, H. Iturra, S. Provencher, D. Cyr, and B. W. Case. 1988. INCREASED INCIDENCE OF MALIGNANT MELANOMA OF THE SKIN IN WORKERS IN A TELECOMMUNICATIONS INDUSTRY. Br J Ind Med 45(12):824-828

de Seze, R., S. Tuffet, B. Veyret, J-M. Moreau, and J. Joussot-Dubien. 1992. EFFECTS OF STRONG UNIFORM PULSED MAGNETIC FIELDS ON GROWTH OF CHEMICALLY-INDUCED MALIGNANT TUMORS AND GRAFTED B16 MELANOMA (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 106

Delgado, J. M. R., J. Leal, J. L. Monteagudo, and M. G. Gracia. 1982. EMBRYOLOGICAL CHANGES INDUCED BY WEAK, EXTREMELY LOW FREQUENCY ELECTROMAGNETIC FIELDS. J Anat 134(3): 533-551

deLorge, J. 1978. EFFECTS OF MAGNETIC FIELDS ON BEHAVIOR IN NONHUMAN PRIMATES (MEETING ABSTRACT). Biomagnetic Effects Workshop, 6-7 April 1978, Lawrence Berkeley Lab., Univ. California, Berkeley, CA (LBL-7452):32-33

Delpizzo, V., and G. Elliott. 1992. IMPACT OF CONCISE INFORMATION ON THE LAYPERSON'S OPINION OF THE RISKS OF CHRONIC EXPOSURE TO ELF MAGNETIC FIELDS (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 10

Demers, P. A., D. B. Thomas, K. A. Rosenblatt, L. M. Jimenez, A. McTiernan, H. Stalsberg, A. Stemhagen, W. D. Thompson, M. G. M. Curnen, W. Satanano, D. F. Austin, P. Isacson, R. S. Greenberg, C. Key, L. N. Kolonel, and D. W. West. 1991. OCCUPATIONAL EXPOSURE TO ELECTROMAGNETIC FIELDS AND BREAST CANCER IN MEN. Am J Epidemiol 134(4):340-347

Dietrich, F., and W. E. Feero. 1992. SAFETY OF HIGH SPEED MAGNETIC LEVITATION TRANSPORTATION SYSTEMS: FINAL REPORT ON MAGNETIC FIELD TESTING OF TR-07 MAGLEV VEHICLE. VOLUME 1 - ANALYSIS. U.S. Dept. of Transportation, Federal Railroad Administration, DOT/FRA/ORD-92/09.I

Dietrich, F. M., W. E. Feero, D. C. Robertson, and G. A. Steiner. 1991. MAGNETIC AND ELECTRIC FIELDS FOR EXISTING AND ADVANCED RAIL TRANSPORTATION SYSTEMS (MEETING ABSTRACT). Annual Review of Research on Biological Effects of 50 and 60 Hz Electric and Magnetic Fields, 3-7 November 1991, Milwaukee, WI, U.S. Dept. of Energy, p. P-23

Dietrich, F. M., W. E. Feero, P. N. Papas, G. A. Steiner, and D. C. Robertson. 1993a. MAGNETIC AND ELECTRIC FIELD TESTING OF THE AMTRAK AND METRO NORTH NORTHEAST CORRIDOR AND NEW JERSEY TRANSIT AND NEW JERSEY COAST LINE RAIL SYSTEMS. VOLUME I - ANALYSIS. VOLUME II - APPENDICES. U.S. DOT, FRA, Washington, DC, DOT-VNTSC-FRA-93-4.I and .II

Dietrich, F. M., P. N. Papas, W. L. Jacobs, and W. E. Feero. 1993b. MAGNETIC AND ELECTRIC FIELD TESTING OF THE FRENCH TRAIN A GRANDE VITESSE-ATLANTIQUE (TGV-A) RAIL SYSTEMS VOLUME I - ANALYSIS. VOLUME II - APPENDICES. U.S. DOT, FRA, Washington, DC, DOT-VNTSC-FRA-93-7.I and .II

Dietrich, et al. (ERM, Inc.). 1993c. MAGNETIC AND ELECTRIC FIELD TESTING OF THE MASSACHUSETTS BAY TRANSPORTATION AUTHORITY (MBTA) URBAN TRANSIT SYSTEM. VOLUME I - ANALYSIS. VOLUME II - APPENDICES. U.S. DOT, FRA, Washington, DC, DOT-VNTSC-FRA-93-6.I and .II

Dlugosz, L., J. Vena, T. Byers, L. Sever, M. Bracken, and E. Marshall. 1992. CONGENITAL DEFECTS AND ELECTRIC BED HEATING IN NEW YORK STATE: A REGISTER-BASED CASE-CONTROL STUDY. Am J Epidemiol 135(9):1000-1011

Dlugosz, L., J. Vena, M. Zielezny, T. Byers, G. Roth, and E. Marshall. 1990. CONGENITAL MALFORMATIONS AND PERICONCEPTIONAL USE OF ELECTRIC BLANKETS AND HEATED WATERBEDS: A REGISTER-BASED CASE-CONTROL STUDY (MEETING ABSTRACT). Society for Epidemiologic Research, 23rd Annual Meeting, 12-15 June, Snowbird Resort, UT, p. 99

Dowson, D. I., G. T. Lewith, M. Campbell, M. A. Mullee, and L. A. Brewster. 1988. OVERHEAD HIGH-VOLTAGE CABLES AND RECURRENT HEADACHE AND DEPRESSIONS. Practitioner 232(1447):435-436

Eckert, E. E. 1976. SUDDEN, UNEXPECTED DEATH OF INFANTS AND ELECTROMAGNETIC FIELDS. Med Klin 71(37):1500-1505

Emilia, G., G. Torelli, G. Ceccherelli, A. Donelli, S. Ferrari, P. Zucchini, and R. Cadossi. 1985. EFFECT OF LOW-FREQUENCY LOW-ENERGY PULSING ELECTROMAGNETIC FIELDS ON THE RESPONSE TO LECTIN STIMULATION OF HUMAN NORMAL AND CHRONIC LYMPHOCYTIC LEUKEMIA LYMPHOCYTES. J Bioelectr 4(1):145-161

Flodin, U., M. Fredricksson, O. Axelson, B. Persson, and L. Hardell. 1986. BACKGROUND RADIATION, ELECTRICAL WORK AND SOME OTHER EXPOSURES ASSOCIATED WITH ACUTE MYELOID LEUKEMIA IN A CASE-REFERENT STUDY. Arch Environ Health 41(2):77-84

Flodin, U., M. Fredricksson, B. Persson, and O. Axelson. 1990. ACUTE MYELOID LEUKEMIA AND BACKGROUND RADIATION IN AN EXPANDED CASE-REFERENT STUDY. Arch Environ Health 45(6): 364-366

Franceschi, C., F. Bersani, and C. Mario. 1986. EXTREMELY LOW FREQUENCY ELECTROMAGNETIC FIELDS (EMF) AFFECT PHYTOHEMAGGLUTININ (PHA) INDUCED BLASTOGENESIS OF HUMAN LYMPHOCYTES (MEETING ABSTRACT). Bioelectromagnetics Society, 8th Annual Meeting, 1-5 June 1986, Madison, WI, p. 29

Frazier, M. E., J. A. Reese, and J. E. Morris. 1988. IN VITRO INVESTIGATION OF 60 Hz AC MAGNETIC FIELDS: ANALYSIS FOR PHENOTYPIC MARKERS OF ACTIVATED ONCOGENES (MEETING ABSTRACT). Biological Effects from Electric and Magnetic Fields, Air Ions and Ion Currents Associated with High Voltage Transmission Lines: Contractors Review. 30 October - 3 November 1988, Phoenix, AZ. U.S. DOE, Office of Energy Storage and Distribution, Washington, DC, and Electric Power Res. Inst., Health Studies Program, Palo Alto, CA

Free, M. J., W. T. Kaune, R. D. Phillips, and H-C. Cheng. 1981. ENDOCRINOLOGICAL EFFECTS OF STRONG 60 Hz ELECTRIC FIELDS ON RATS. Bioelectromagnetics 2(2):105-121

Frolen, H., B. M. Svedenstal, P. Bierke, and H. Fellner-Feldegg. 1987. EXTENDED STUDIES ON THE EFFECTS OF PULSED MAGNETIC FIELDS ON THE EMBRYONIC DEVELOPMENT IN MICE. Swedish Agricultural Univ., Project SSI 346, 86. Final Report (June 1987)

Fulton, J. P., S. Cobb, L. Preble, L. Leone, and E. Forman. 1980. ELECTRICAL WIRING CONFIGURATIONS AND CHILDHOOD LEUKEMIA IN RHODE ISLAND. Am J Epidemiol 111(3):292-296

Gallagher, R. P., P. R. Band, J. J. Spinelli, W. J. Threlfall, and S. Tamaro. 1991. BRAIN CANCER AND EXPOSURE TO ELECTROMAGNETIC FIELDS. J Occup Med 33(9):944-945

Gamberale, F. 1990. PHYSIOLOGICAL AND PSYCHOLOGICAL EFFECTS OF EXPOSURE TO EXTREMELY LOW-FREQUENCY ELECTRIC AND MAGNETIC FIELDS ON HUMANS. Scand J Work Environ Health 16(suppl. 1):51-54

Gamberale, F., B. Anshelm Olson, P. Eneroth, T. Lindh, and A. Wennberg. 1989. ACUTE EFFECTS OF ELF ELECTROMAGNETIC FIELDS: A FIELD STUDY OF LINESMEN WORKING WITH 400 KV POWER LINES. Br J Ind Med 46(10):729-737

Garber, H. J., W. H. Oldendorf, L. D. Braun, and R. B. Lufkin. 1989. MR GRADIENT FIELDS INCREASE BRAIN MANNITOL SPACE (MEETING ABSTRACT). Society for Magnetic Resonance Imaging, 7th Annual Meeting, 25 February - 1 March 1989, Los Angeles, CA, p. 59

Garland, F. C., E. Shaw, E. D. Gorham, C. F. Garland, M. R. White, and P. J. Sinsheimer. 1990. INCIDENCE OF LEUKEMIA IN OCCUPATIONS WITH POTENTIAL ELECTROMAGNETIC FIELD EXPOSURE IN UNITED STATES NAVY PERSONNEL. Am J Epidemiol 132(2):293-303

Gilman, P. A., R. G. Ames, and M. A. McCawley. 1985. LEUKEMIA RISK AMONG U.S. WHITE MALE COAL MINERS. A CASE-CONTROL STUDY. J Occup Med 27(9):669-671

Goldberg, R. B., and W. A. Creasey. 1991. A REVIEW OF CANCER INDUCTION BY EXTREMELY LOW FREQUENCY ELECTROMAGNETIC FIELDS. IS THERE A PLAUSIBLE MECHANISM? Med Hypotheses 35(3):265-274

Goodman, R., and A. S. Henderson. 1987. PATTERNS OF TRANSCRIPTION AND TRANSLATION IN CELLS EXPOSED TO EM FIELDS: A REVIEW. Mechanistic Approaches to Interactions of Electric and Electromagnetic Fields with Living Systems. M. Blank, E. Findl, eds. New York: Plenum Press, p. 217-230

Graham, C., H. D. Cohen, M. R. Cook, M. M. Gerkovich, and D. R. Riffle. 1988. EFFECTS OF INTERMITTENT EXPOSURE TO 60 Hz FIELDS ON HUMAN PHYSIOLOGY (MEETING ABSTRACT). Biological Effects from Electric and Magnetic Fields, Air Ions and Ion Currents Associated with High Voltage Transmission Lines: Contractors Review. 30 October - 3 November 1988, Phoenix, AZ. U.S. DOE, Office of Energy Storage and Distribution, Washington, DC, and Electric Power Res. Inst., Health Studies Program, Palo Alto, CA

Graham, C., H. D. Cohen, M. R. Cook, M. M. Gerkovich, D. R. Riffle, and S. J. Hoffman. 1991a. HUMAN CARDIAC ACTIVITY IN 60 Hz MAGNETIC FIELDS (MEETING ABSTRACT). Bioelectromagnetics Society, 13th Annual Meeting, 23-27 June, Salt Lake City, UT, p. 54

Graham, C., H. D. Cohen, M. R. Cook, M. M. Gerkovich, and D. W. Riffle. 1991b. INDIVIDUAL DIFFERENCES IN CARDIAC RESPONSIVITY TO 60 Hz FIELD (MEETING ABSTRACT). Annual Review of Research on Biological Effects of 50 and 60 Hz Electric and Magnetic Fields, 3-7 November 1991, Milwaukee, WI, U.S. Dept. of Energy, p. A-33

Graves, H. B. 1982. EFFECTS OF 60 HZ ELECTRIC FIELDS ON CHICK EMBRYOS (MEETING ABSTRACT). Bioelectromagnetics Society, 4th Annual Meeting, June 28 - July 2, 1982, Los Angeles, CA, p. 6

Groh, K. R., C. F. Ehret, and M. A. Readey. 1988. THE ACTIONS OF HIGH-STRENGTH 60 HZ ELECTRIC FIELDS ON CIRCADIAN RHYTHMS IN SMALL RODENTS (MEETING ABSTRACT). Biological Effects from Electric and Magnetic Fields, Air Ions and Ion Currents Associated with High Voltage Transmission Lines: Contractors Review. 30 October - 3 November 1988, Phoenix, AZ. U.S. DOE, Office of Energy Storage and Distribution, Washington, DC, and Electric Power Res. Inst., Health Studies Program, Palo Alto, CA

Groh, K. R., and M. A. Readey. 1990. CHRONOBIOLOGICAL EFFECTS OF 60 Hz ELECTRIC FIELDS IN RODENTS (MEETING ABSTRACT). Annual Review of Research on Biological Effects of 50 and 60 Hz Electric and Magnetic Fields, 5-8 November 1990, Denver, CO, U.S. Dept. of Energy, p. A21

Guenel, P., P. Raskmark, J. B. Adersen, and E. Lynge. 1992. OCCURRENCE OF CANCER IN DANES WHO HAVE BEEN EXPOSED TO MAGNETIC FIELDS IN THEIR WORK. Cancer Registry of the Danish Cancer Control Agency, Copenhagen, October 6, 10 pp.

Haupt, R. C., and J. R. Nolfi. 1984. THE EFFECTS OF HIGH VOLTAGE TRANSMISSION LINES ON THE HEALTH OF ADJACENT RESIDENT POPULATIONS. Am J Public Health 74(1):76-78

Haysom, C., D. I. Dowson, and M. J. Campbell. 1990. THE RELEVANCE OF HEADACHES AND MIGRAINE IN POPULATIONS RESIDENT NEAR OVERHEAD POWER LINES - AN EPIDEMIOLOGICAL STUDY. Complementary Med Res 4(1):12-15

Hellman, K. B., P. P. Brewer, A. K. Fowler, A. Hellman, and M. L. Swicord. 1985. THE EFFECT OF ELECTROMAGNETIC FIELDS ON LYMPHOCYTE FUNCTION: ENHANCEMENT OF MITOGENIC STIMULATION (MEETING ABSTRACT). Bioelectromagnetics Society, 7th Annual Meeting, 16-20 June, San Francisco, CA, p. C-6

Hersh, G., and V. Pura. 1992. PRUDENT AVOIDANCE: CONCEPT, DEFINITIONS, USES (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 10

Hesketh, R., G. A. Smith, and J. C. Metcalf. 1987. INTRACELLULAR CALCIUM AND NORMAL EUKARYOTIC CELL GROWTH. Control of Animal Cell Proliferation. Vol 1. (A. L. Boynton, H. L. Leffert, eds.) Academic Press, New York, p. 395

Hojevik, P., Y. Hamnerius, and S. Galt. 1991. REDUCTION OF MAGNETIC FIELDS FROM VIDEO DISPLAY TERMINALS (MEETING ABSTRACT). Bioelectromagnetics Society, 13th Annual Meeting, 23-27 June, Salt Lake City, UT, p. 55

Iur'ev, V. N., and N. V. Krasnogorskaia. 1980. EFFECT OF FLUCTUATING MAGNETIC FIELDS ON GROWTH AND TUMORIGENESIS. Biull Eksp Biol Med 90(11):602-604

Johnson, T. R., J. Dabkowski, and J. E. Stangel. 1991. POWER FREQUENCY MAGNETIC FIELD SOURCES AND EXPOSURE REDUCTION OPTIONS (MEETING ABSTRACT). Annual Review of Research on Biological Effects of 50 and 60 Hz Electric and Magnetic Fields, 3-7 November 1991, Milwaukee, WI, U.S. Dept. of Energy, p. P-2

Jolley, W. B., D. B. Hinshaw, K. Knierim, and D. B. Hinshaw. 1983. MAGNETIC FIELD EFFECTS ON CALCIUM EFFLUX AND INSULIN SECRETION IN ISOLATED RABBIT ISLETS OF LANGERHANS. Bioelectromagnetics 4(1):103-106

Kanal, E., J. Evans, J. Gillen, D. A. Savitz, and F. G. Shellock. 1992. SURVEY OF REPRODUCTIVE HEALTH AMONG FEMALE MR OPERATORS (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 73

Kartashev, A. G., and L. A. Ivanova. 1988. CHRONIC EFFECT OF AN ALTERNATING ELECTRIC FIELD ON THE ENDOCRINE SYSTEM OF ALBINO MICE. Gig Sanit (5):9-12

Kaune, W. T., S. West, M. Flynn, J. M. Silva, and D. A. Savitz. 1989. EXPOSURE OF ELECTRIC UTILITY WORKERS TO POWER-FREQUENCY MAGNETIC FIELDS (MEETING ABSTRACT). Bioelectromagnetics Society, 11th Annual Meeting, 18-22 June, Tucson, AZ, p. 46-47

Kaye, G. C., G. S. Butrous, A. Allen, S. J. Meldrum, J. C. Male, and A. J. Camm. 1988. THE EFFECT OF 50 HZ EXTERNAL ELECTRICAL INTERFERENCE ON IMPLANTED CARDIAC PACEMAKERS. PACE 11 (7): 999-1008

Knave, B., and B. Floderus. 1988. EXPOSURE TO LOW-FREQUENCY ELECTROMAGNETIC FIELDS -- A HEALTH HAZARD? Scand J Work Environ Health 14(sup 1):46-48

Knave, B., B. Floderus-Myrhed, S. Tornqvist, T. Lindh, and C. Stenlund. 1987. OCCUPATIONAL HYGIENE STUDY OF WORKERS EXPOSED TO LOW-FREQUENCY MAGNETIC FIELDS (POSTER SESSION). Biological Effects From Electric and Magnetic Fields, Air Ions and Ion Currents Associated with High Voltage Transmission Lines: Contractors Review. 1-4 November 1987, Kansas City, MO. U.S. Dept. of Energy, Office of Energy Storage and Distribution, Washington, D.C. 20585, and Electric Power Res. Inst., Health Studies Program, Palo Alto, CA.

Knave, B., F. Gamberale, S. Bergstrom, E. Birke, A. Iregren, B. Kolmodin-Hedman, and A. Wennberg. 1979. LONG-TERM EXPOSURE TO ELECTRIC FIELDS. A CROSS-SECTIONAL EPIDEMIOLOGIC INVESTIGATION OF OCCUPATIONALLY EXPOSED WORKERS IN HIGH VOLTAGE SUBSTATIONS. Scand J Work Environ Health 5(2):115-125

Knave, B. G. 1988. WHAT DO EPIDEMIOLOGICAL STUDIES TELL US? Non-ionizing Radiations: Physical Characteristics, Biological Effects and Health Hazard Assessment (Addendum). Proceedings of the International Non-Ionizing Radiation Workshop, 5-9 April 1988, Melbourne, Australia, M. H. Repacholi, ed., London: International Radiation Protection Association Publications, 10 pp.

Kuijten, R. R., G. R. Bunin, C. C. Nass, and A. T. Meadows. 1992. PARENTAL OCCUPATION AND CHILDHOOD ASTROCYTOMA: RESULTS OF A CASE-CONTROL STUDY. Cancer Res 52(3):782-786

Leal, J., K. Shamsaifar, M. A. Trillo, A. Ubeda, V. Abraira, and L. Chacon. 1989. EMBRYONIC DEVELOPMENT AND WEAK CHANGES OF THE GEOMAGNETIC FIELD. J Bioelectricity 7(2):141-153

Lednev, V. V. 1991. POSSIBLE MECHANISM FOR THE INFLUENCE OF WEAK MAGNETIC FIELDS ON BIOLOGICAL SYSTEMS. Bioelectromagnetics 12(2):71-75

Lednev, V. V. 1992. PARAMETRIC RESONANCE MODEL FOR THE INTERACTION OF MAGNETIC FIELDS WITH BIOSYSTEMS: THEORETICAL PREDICTIONS AND THEIR EXPERIMENTAL VERIFICATION (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 49

Lerchl, A., K. O. Nonaka, K-A. Stokkan, and R. J. Reiter. 1991. HIGH DB/DT MAGNETIC FIELDS AFFECT PINEAL MELATONIN SYNTHESIS IN VIVO (MEETING ABSTRACT). Bioelectromagnetics Society, 13th Annual Meeting, 23-27 June, Salt Lake City, UT, p. 80

Leung, F. C., C. A. Poindexter, D. N. Rommereim, J. A. Creim, and L. E. Anderson. 1988. EVIDENCE OF STRESS IN RATS EXPOSED TO 60 Hz ELECTRIC FIELDS (MEETING ABSTRACT). Biological Effects from Electric and Magnetic Fields, Air Ions and Ion Currents Associated with High Voltage Transmission Lines: Contractors Review. 30 October - 3 November 1988, Phoenix, AZ. U.S. DOE, Office of Energy Storage and Distribution, Washington, DC, and Electric Power Res. Inst., Health Studies Program, Palo Alto, CA

Leung, F. C., D. N. Rommereim, R. A. Miller, and L. E. Anderson. 1990. BROWN-COLORED DEPOSITS ON HAIR OF FEMALE RATS CHRONICALLY EXPOSED TO 60 Hz ELECTRIC FIELDS. Bioelectromagnetics 11(3):257-259

Leung, F. C., D. N. Rommereim, R. G. Stevens, B. W. Wilson, R. L. Buschbom, and L. E. Anderson. 1988. EFFECTS OF ELECTRIC FIELDS ON RAT MAMMARY TUMOR DEVELOPMENT INDUCED BY 7,12-DIMETHYLBENZ(A)ANTHRACENE (MEETING ABSTRACT). Bioelectromagnetics Society, 10th Annual Meeting, 19-24 June, Stamford, CT, p. 2-3

Lewy, A. J. 1989. SEASONAL AFFECTIVE DISORDER: PINEAL FUNCTION AND DEPRESSION IN HUMANS (MEETING ABSTRACT). Bioelectromagnetics Society, 11th Annual Meeting, 18-22 June, Tucson, AZ, p. 1

Liboff, A. R., B. R. McLeod, and S. D. Smith. 1989. ION CYCLOTRON RESONANCE EFFECTS OF ELF FIELDS IN BIOLOGICAL SYSTEMS. Extremely Low Frequency Electromagnetic Fields: The Question of Cancer. B. W. Wilson, R. G. Stevens, L. E. Anderson, eds., Columbus, OH: Battelle Press, p. 251-289

Liboff, A. R., J. R. Thomas, and J. Schrot. 1989. INTENSITY THRESHOLD FOR 60 HZ MAGNETICALLY INDUCED BEHAVIORAL CHANGES IN RATS. Bioelectromagnetics 10(1):111-113

Liburdy, R. P., R. L. Miller, and C. H. Durney. 1988. MAGNETIC FIELD INTERACTION WITH CALCIUM IONS IN THE LYMPHOCYTE (MEETING ABSTRACT). Bioelectromagnetics Society, 10th Annual Meeting, 19-24 June, Stamford, CT, p. 40

Lin, R. 1987. MORTALITY PATTERNS AMONG EMPLOYEES OF ELECTRIC POWER COMPANY IN TAIWAN (MEETING ABSTRACT). Biological Effects From Electric and Magnetic Fields, Air Ions and Ion Currents Associated with High Voltage Transmission Lines: Contractors Review. 1-4 November 1987, Kansas City, MO. U.S. Dept. of Energy, Office of Energy Storage and Distribution, Washington, D.C. 20585, and Electric Power Res. Inst., Health Studies Program, Palo Alto, CA 94303.

Lin, R. S. 1988. CANCER MORTALITY PATTERNS AMONG EMPLOYEES OF TELECOMMUNICATION INDUSTRY IN TAIWAN (MEETING ABSTRACT). Biological Effects from Electric and Magnetic Fields, Air Ions and Ion Currents Associated with High Voltage Transmission Lines: Contractors Review. 30 October - 3 November 1988, Phoenix, AZ. U.S. DOE, Office of Energy Storage and Distribution, Washington, DC, and Electric Power Res. Inst., Health Studies Program, Palo Alto, CA

Lin, R. S., P. C. Dischinger, J. Conde, and K. P. Farrell. 1985. OCCUPATIONAL EXPOSURE TO ELECTROMAGNETIC FIELDS AND THE OCCURRENCE OF BRAIN TUMORS. AN ANALYSIS OF POSSIBLE ASSOCIATIONS. J Occup Med 27(6):413-419

Lin, R. S., and C-Y. Li. 1992. RISK OF CHILDHOOD LEUKEMIA IN HIGH POWER LINE PASSING AREAS--EPIDEMIOLOGIC FINDINGS IN TAIWAN (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 77-78

Lindh, T., and L-I. Andersson. 1988. COMPARISON BETWEEN TWO POWER-FREQUENCY ELECTRIC-FIELD DOSIMETERS. Scand J Work Environ Health 14(sup 1):43-45

Linet, M. S., H. S. R. Malker, J. K. McLaughlin, J. A. Weiner, B. J. Stone, W. J. Blot, J. L. E. Ericsson, and J. F. Fraumeni Jr. 1988. LEUKEMIAS AND OCCUPATION IN SWEDEN: A REGISTRY-BASED ANALYSIS. Am J Ind Med 14(3):319-330

Liubchenko, S. A. 1982. THE EFFECT OF AN ELECTRIC FIELD OF INDUSTRIAL FREQUENCY ON THE INDICES OF NATURAL IMMUNITY. Vrach Delo (8):103-105

London, S. J., D. C. Thomas, J. D. Bowman, E. Sobel, T-C. Cheng, and J. M. Peters. 1991. EXPOSURE TO RESIDENTIAL ELECTRIC AND MAGNETIC FIELDS AND RISK OF CHILDHOOD LEUKEMIA. Am J Epidemiol 134(9):923-937

Loomis, D. P. 1992. CANCER OF BREAST AMONG MEN IN ELECTRICAL OCCUPATIONS (LETTER). Lancet 339 (8807):1482-1483

Loomis, D. P., and D. A. Savitz. 1990. MORTALITY FROM BRAIN CANCER AND LEUKAEMIA AMONG ELECTRICAL WORKERS. Br J Ind Med 47(9):633-638

Lotz, W. G., and J. L. Saxton. 1984. ASSESSMENT OF ELF GROWTH EFFECTS IN YOUNG RHESUS MONKEYS (MEETING ABSTRACT). Bioelectromagnetics Society, 6th Annual Meeting, 15-19 July, Atlanta, GA, p. 9

Lovely, R. H. 1988. RECENT STUDIES IN THE BEHAVIORAL TOXICOLOGY OF ELF ELECTRIC AND MAGNETIC FIELDS. Electromagnetic Fields and Neurobehavioral Function, M. E. O'Connor and R. H. Lovely, eds., New York: Alan R. Liss, Inc.: 327-347

Lovely, R. H., J. A. Creim, D. L. Miller, R. L. Buschbom, and L. E. Anderson. 1992a. EXPOSURE TO MAGNETIC FIELDS DURING SPATIAL LEARNING INCREASES ERROR RATES IN RATS: EARLY STUDIES (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 23

Lovely, R. H., J. A. Creim, D. L. Miller, R. L. Buschbom, and L. E. Anderson. 1992b. EXPOSURE TO MAGNETIC FIELDS DURING SPATIAL LEARNING INCREASES ERROR RATES IN RATS: EARLY STUDIES (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 122

Lovely, R. H., J. A. Creim, and R. D. Phillips. 1982. EARLY NEUROMUSCULAR DEVELOPMENT IN THREE-DAY-OLD F-2 GENERATION MINIATURE SWINE IS UNAFFECTED BY PRENATAL EXPOSURE TO 60 Hz ELECTRIC FIELDS (MEETING ABSTRACT). Bioelectromagnetics Society, 4th Annual Meeting, June 28 - July 2, 1982, Los Angeles, CA, p. 7

Luben, R. A. 1992. EFFECTS OF LOW ENERGY ELECTROMAGNETIC FIELDS (LEMF) ON SIGNAL TRANSDUCTION BY G PROTEIN LINKED RECEPTORS (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 4

Luben, R. A., D. Huynh, and A. Morgan. 1991. IN VITRO EFFECTS OF LOW ENERGY ELECTROMAGNETIC FIELDS (LEMF) ON BETA-ADRENERGIC RECEPTOR FUNCTION IN MOUSE BONE CELLS, FIBROBLASTS AND PINEAL ORGAN CULTURES (MEETING ABSTRACT). Annual Review of Research on Biological Effects of 50 and 60 Hz Electric and Magnetic Fields, 3-7 November 1991, Milwaukee, WI, U.S. Dept. of Energy, p. A-15

Luben, R. A., A. Carlson, and A. P. Morgan. 1992. TIME, DOSE AND INTERMITTENCY OPTIMA ('WINDOWS') IN THE RESPONSES OF G PROTEIN LINKED MEMBRANE RECEPTORS TO LOW ENERGY ELECTROMAGNETIC FIELDS: PARATHYROID HORMONE AND ISOPROTERENOL RECEPTORS IN BONE CELLS (MEETING ABSTRACT). Annual Review of Research on Biological Effects of Electric and Magnetic Fields from the Generation, Delivery and Use of Electricity Meeting, 8-12 November, San Diego, CA, U.S. Dept. of Energy, p. A-12

Lyle, D. B., R. D. Ayotte, A. R. Sheppard, and W. R. Adey. 1988. SUPPRESSION OF T-LYMPHOCYTE CYTOTOXICITY FOLLOWING EXPOSURE TO 60 Hz SINUSOIDAL ELECTRIC FIELDS. Bioelectromagnetics 9(3):303-313

Lymangrover, J. R., E. Keku, S. T. Hsieh, W. P. Dunlap, and Y. J. Seto. 1987. DIRECT POWER-FREQUENCY ELECTRIC FIELD EFFECTS ON MAMMALIAN ENDOCRINE TISSUE. Environ Res 43(1):157-167

Maestroni, G. J., A. Conti, and W. Pierpaoli. 1987. PINEAL MELATONIN. ITS FUNDAMENTAL IMMUNOREGULATORY ROLE IN AGING AND CANCER. Neuroimmunomodulation. Interventions in Aging and Cancer. First Stomboli Conference on Aging and Cancer (NATO Advanced Research Workshop), p. 12

Marcer, M., G. Musatti, and C. A. L. Bassett. 1984. RESULTS OF PULSED ELECTROMAGNETIC FIELDS (PEMFS) IN UNUNITED FRACTURES AFTER EXTERNAL SKELETAL FIXATION. Clin Orthop (190): 260-265

Marsakova, N. V. 1982. CHANGES IN IODINE CONTENT IN THE RAT ORGANISM DURING EXPOSURE TO AN ALTERNATING-MAGNETIC-FIELD (MEETING ABSTRACT). All-Union Symposium on the Biological Effects of Electromagnetic Fields, Pushchino, USSR, p. 57

Martin, A. H. 1988. MAGNETIC FIELDS AND TIME DEPENDENT EFFECTS ON DEVELOPMENT. Bioelectromagnetics 9(4):393-396

Matanoski, G. M., P. N. Breysse, and E. A. Elliott. 1991. ELECTROMAGNETIC FIELD EXPOSURE AND MALE BREAST CANCER. Lancet 337(8743):737

Matanoski, G. M., E. A. Elliott, P. N. Breysse, and M. C. Lynberg. 1993. LEUKEMIA IN TELEPHONE LINEMEN. Am J Epidemiol 137 (6):609-619

McCoy, S. L., B. E. Ogden, A. S. Hall, and S. H. Hefeneider. 1992. EFFECT OF WHOLE BODY EMF EXPOSURE ON INTERLEUKIN-1 PRODUCTION AND ANTIBODY DEVELOPMENT (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 109

McDowall, M. E. 1983. LEUKEMIA MORTALITY IN ELECTRICAL WORKERS IN ENGLAND AND WALES (LETTER). Lancet 1(8318):246

McDowall, M. E. 1986. MORTALITY OF PERSONS RESIDENT IN THE VICINITY OF ELECTRICITY TRANSMISSION FACILITIES. Br J Cancer 53(2):271-279

McLaughlin, J. K., H. S. R. Malker, W. J. Blot, B. K. Malker, B. J. Stone, J. A. Weiner, J. L. E. Ericsson, and J. F. Fraumeni Jr. 1987. OCCUPATIONAL RISKS FOR INTRACRANIAL GLIOMAS IN SWEDEN. J Natl Cancer Inst 78(2):253-257

McLean, J. R. N., M. A. Stuchly, R. E. J. Mitchel, D. Wilkinson, H. Yang, M. Goddard, D. W. Lecuyer, M. Schunk, E. Callary, and D. Morrison. 1991. CANCER PROMOTION IN A MOUSE-SKIN MODEL BY A 60 Hz MAGNETIC FIELD: II. TUMOR DEVELOPMENT AND IMMUNE RESPONSE. Bioelectromagnetics 12(5):273-287

McLean, J. R. N., A. Thansandote, D. W. Lecuyer, C. Davidson, M. J. Goddard, and R. Burnett. 1993. THE EFFECT OF MAGNETIC FIELDS ON TUMOR CO-PROMOTION IN SENCAR MOUSE SKIN (MEETING ABSTRACT). Bioelectromagnetics Society, 15th Annual Meeting, 13-17 June, Los Angeles, CA, p. 153

McMahan, S. G. 1992. RESIDENTIAL PROXIMITY TO HIGH VOLTAGE TRANSMISSION LINES AND DEPRESSIVE SYMPTOMATOLOGY (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 77

Mehta, S., M. Lefebvre, D. Cherlin, M. Wiesendanger, and C. Polk. 1991. HUMAN IMMUNE CELL FUNCTION IN LOW FREQUENCY ELECTRIC AND MAGNETIC ENVIRONMENT (MEETING ABSTRACT). Annual Review of Research on Biological Effects of 50 and 60 Hz Electric and Magnetic Fields, 3-7 November 1991, Milwaukee, WI, U.S. DOE, p. A-16

Mevissen, M., W. Loscher, A. Weismann, and A. Stamm. 1993a. EXPOSURE OF RATS TO A 50 Hz, 100 UT MAGNETIC FIELD INCREASES THE INCIDENCE OF MAMMARY TUMORS IN A DMBA-MODEL OF BREAST CANCER (MEETING ABSTRACT). Bioelectromagnetics Society, 15th Annual Meeting, 13-17 June, Los Angeles, CA, p. 80-81

Mevissen, M., A. Stamm, S. Buntenkotter, R. Zwingelberg, U. Wahnschaffe, and W. Loscher. 1993b. EFFECTS OF MAGNETIC FIELDS ON MAMMARY TUMOR DEVELOPMENT INDUCED BY 7,12-DIMETHYLBE-NZ(A)ANTHRACENE IN RATS. Bioelectromagnetics 14 (2):131-143

Michaelson, S. M. 1987. INFLUENCE OF POWER FREQUENCY ELECTRIC AND MAGNETIC FIELDS ON HUMAN HEALTH. Ann N Y Acad Sci 502:55-75

Michaelson, S. M., and S-T. Lu. 1988. ELECTRIC FIELD EXPOSURE AND PHYSIOLOGIC 'STRESS' (MEETING ABSTRACT). Biological Effects from Electric and Magnetic Fields, Air Ions and Ion Currents Associated with High Voltage Transmission Lines: Contractors Review. 30 October - 3 November 1988, Phoenix, AZ. U.S. DOE, Office of Energy Storage and Distribution, Washington, DC, and Electric Power Res. Inst., Health Studies Program, Palo Alto, CA

Mikhail, E. L., and W. Z. Fam. 1992. INCIDENCE OF LYMPHOMA IN CFW MICE CHRONICALLY EXPOSED TO LOW-FREQUENCY ELECTROMAGNETIC FIELDS (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 28

Milham, S. 1982. MORTALITY FROM LEUKEMIA IN WORKERS EXPOSED TO ELECTRICAL AND MAGNETIC FIELDS (LETTER TO EDITOR). N Engl J Med 307(4):249

Milham, S., Jr. 1985a. MORTALITY IN WORKERS EXPOSED TO ELECTROMAGNETIC FIELDS. Environ Health Perspect 62:297-300

Milham, S., Jr. 1985b. SILENT KEYS: LEUKAEMIA MORTALITY IN AMATEUR RADIO OPERATORS (LETTER). Lancet (8432):812

Morris, J. E. 1985. IMMUNE SYSTEM RESPONSES AND 60 Hz ELECTRIC FIELDS (MEETING ABSTRACT). Bioelectromagnetics Society, 7th Annual Meeting, 16-20 June, San Francisco, CA, J-28

Morris, J. E., M. E. Frazier, B. J. McClanahan, R. L. Buschbom, and L. E. Anderson. 1989. CELL-MEDIATED IMMUNITY IN RATS EXPOSED TO 60 Hz ELECTRIC FIELDS (MEETING ABSTRACT). Bioelectromagnetics Society, 11th Annual Meeting, 18-22 June, Tucson, AZ, p. 64

Morris, J. E., and B. J. McClanahan. 1986. IN VITRO EXPOSURE OF LYMPHOCYTES TO 60 Hz ELECTRIC AND MAGNETIC FIELDS (MEETING ABSTRACT). Bioelectromagnetics Society, 8th Annual Meeting, 1-5 June 1986, Madison, WI, p. 64

Morris, J. E., and R. D. Phillips. 1982. EFFECTS OF 60 Hz ELECTRIC FIELDS ON SPECIFIC HUMORAL AND CELLULAR COMPONENTS OF THE IMMUNE SYSTEM. Bioelectromagnetics 3(3):341-347

Moss, C. E., and J. M. Boiano. 1988. HEALTH HAZARD EVALUATION REPORT HETA 87-329-1898, FERMILAB, BATAVIA, ILLINOIS. NTIS Document No. PB89-120646/XAB; 22 pp. Report No. HETA-87-329-1898

Myers, A., A. D. Clayden, R. A. Cartwright, and S. C. Cartwright. 1990. CHILDHOOD CANCER AND OVERHEAD POWERLINES: A CASE-CONTROL STUDY. Br J Cancer 62(6):1008-1014

Nakagawa, M. 1992. EMF ISSUES WITH MAGLEV IN JAPAN (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 66

Nakagawa, M., and Y. Matsuda. 1988. A STRONG STATIC-MAGNETIC FIELD ALTERS OPERANT RESPONDING BY RATS. Bioelectromagnetics 9(1):25-37

Nakagawa, M., M. Tomita, T. Koana, M. Odaka, and K. Ohno. 1992. ESTIMATION OF STANDARDIZED MORTALITY RATES IN JNR (JPN. NATIONAL RAILWAYS) COHORT BY OCCUPATION (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 76

Nguyen, D., A. P. Morgan, and R. A. Luben. 1992. LOW ENERGY ELECTROMAGNETIC FIELDS AND GROWTH REGULATORY SIGNAL TRANSDUCTION: MODULATION OF PROTEIN KINASE C ACTIVATION IN BONE CELLS BY ONE GAUSS, 60 HZ SINE WAVE FIELDS (MEETING ABSTRACT). Annual Review of Research on Biological Effects of Electric and Magnetic Fields from the Generation, Delivery and Use of Electricity Meeting, 8-12 November, San Diego, CA, U.S. DOE, P-9

Niple, J. C., J. M. Silva, and W. T. Kaune. 1989. AC MAGNETIC FIELD INSTRUMENTS FOR THE STUDY OF MAGNETIC FIELD EXPOSURE (MEETING ABSTRACT). Annual Review of Research on Biological Effects of 50 and 60 Hz Electric and Magnetic Fields, 13-16 November 1989, Portland, OR, U.S. DOE, p. P-2

Nordenson, I., K. Hansson Mild, U. Ostman, and H. Ljungberg. 1988. CHROMOSOMAL EFFECTS IN LYMPHOCYTES OF 400 KV-SUBSTATION WORKERS. Radiat Environ Biophys 27(1):39-47

Nordstrom, S., E. Birke, and L. Gustavsson. 1983. REPRODUCTIVE HAZARDS AMONG WORKERS AT HIGH VOLTAGE SUBSTATIONS. Bioelectromagnetics 4(1):91-101

Ohm, O. J. 1976. INTERFERENCE WITH CARDIAC PACEMAKER FUNCTION. Acta Med Scand 596 (Suppl.):87-95

Olin, R., D. Vagero, and A. Ahlbom. 1985. MORTALITY EXPERIENCE OF ELECTRICAL ENGINEERS. Br J Ind Med 42:211-212

Olsen, J. H., P. de Nully Brown, G. Schulgen, and O. M. Jensen. 1991. PARENTAL EMPLOYMENT AT TIME OF CONCEPTION AND RISK OF CANCER IN OFFSPRING. Eur J Cancer 27(8):958-965

Olsen, J. H., A. Nielsen, G Schulgen, A. Bautz, and V. B. Larsen. 1992. RESIDENCE CLOSE TO HIGH-VOLTAGE ELECTRICAL INSTALLATIONS AND RISK OF DEVELOPMENT OF CANCER IN CHILDREN. Cancer Registry of the Danish Cancer Control Agency, Copenhagen, 6 October, 19 pp.

Olshan, A. F., P. A. Baird, and K. Teschke. 1988. PATERNAL OCCUPATION AS A RISK FACTOR FOR BIRTH DEFECTS (MEETING ABSTRACT). Am J Epidemiol 128(4):911 Society for Epidemiologic Research, 21st Annual Meeting, June 1988

Orr, J. L., and W. R. Rogers. 1991. BABOON WORK-STOPPAGE AND 60 Hz ELECTRIC AND MAGNETIC FIELDS (MEETING ABSTRACT). Annual Review of Research on Biological Effects of 50 and 60 Hz Electric and Magnetic Fields, 3-7 November 1991, Milwaukee, WI, U.S. Dept. of Energy, p. A-31

Orr, J. L., and W. R. Rogers. 1992. BABOON WORK-STOPPAGE: 60 Hz ELECTRIC AND MAGNETIC FIELDS (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 23

Ossenkopp, K-P., and M. Kavaliers. 1989. CLINICAL AND APPLIED ASPECTS OF MAGNETIC FIELD EXPOSURE: A POSSIBLE ROLE FOR THE ENDOGENOUS OPIOID SYSTEM. J Bioelectricity 7(2):189-208

Pastides, H., J. R. Miller, K. A. Mundt, J. Klar, R. F. Adams, and T. Olendorf. 1991. A CHARACTERIZATION OF OCCUPATIONAL STATIC MAGNETIC FIELD EXPOSURES AT A DIAPHRAGM-CELL AND A MERCURY-CELL CHLOR-ALKALI FACILITY. Appl Occup Environ Hyg 7(1):42-48

Pearce, N. E., R. A. Sheppard, J. K. Howard, J. Fraser, and B. M. Lilley. 1985. LEUKAEMIA IN ELECTRICAL WORKERS IN NEW ZEALAND (LETTER). Lancet (8432):811-812

Perry, F. S., M. Reichmanis, A. A. Marino, and R. O. Becker. 1981. ENVIRONMENTAL POWER-FREQUENCY MAGNETIC FIELDS AND SUICIDE. Health Phys 41(2):267-277

Persson, B. R. R., L. G. Salford, A. Brun, J. Eberhardt, and L. Malmgren. 1991. PERMEABILITY OF THE BLOOD-BRAIN BARRIER INDUCED BY MAGNETIC AND ELECTROMAGNETIC FIELDS (MEETING ABSTRACT). Biological Effects and Safety Aspects of Nuclear Magnetic Resonance Imaging and Spectroscopy, 15-17 May, 1991, New York Academy of Sciences

Phillips, J. L. 1986. TRANSFERRIN RECEPTORS AND NATURAL KILLER CELL LYSIS. A STUDY USING COLO 205 CELLS EXPOSED TO 60 HZ ELECTROMAGNETIC FIELDS. Immunol Lett 13(6):295-299

Poole, C., R. Kavet, D. P. Funch, K. Donelan, and J. M. Charry. 1992. PREVALENCE OF DEPRESSIVE SYMPTOMS AND HEADACHE IN TOWNS ALONG A TRANSMISSION-LINE CORRIDOR (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 77

Portet, R., and J. Cabanes. 1988. DEVELOPMENT OF YOUNG RATS AND RABBITS EXPOSED TO A STRONG ELECTRIC FIELD. Bioelectromagnetics 9(1):95-104

Prato, F. S., R. H. Frappier, R. R. Shivers, M. Kavaliers, P. Zabel, D. J. Drost, and T. Y. Lee. 1990. MAGNETIC RESONANCE IMAGING INCREASES THE BRAIN SPACE OF 153 GADOLINIUM DIETHYLENETRIAMINEPENTAACETIC ACID IN RATS (MEETING ABSTRACT). Bioelectromagnetics Society, 12th Annual Meeting, 10-14 June, San Antonio, TX, p. 46

Prato, F. S., R. H. Frappier, J. M. Wills, and R. R. Shivers. 1992. BLOOD-BRAIN BARRIER PERMEABILITY IN RATS IS NOT ALTERED BY EXPOSURE TO MAGNETIC RESONANCE IMAGING AT 1.5 TESLA (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 73

Prato, F. S., R. L. Nicholson, M. Smith, and D. J. Drost. 1986. HAZARDS AND ASSOCIATED RECOMMENDATIONS FOR CANADIAN MR IMAGING SITES. Can Assoc Radiol J 37(4):233-237

Preston, E., K. Butler, and N. Haas. 1989. DOES MAGNETIC RESONANCE IMAGING COMPROMISE INTEGRITY OF THE BLOOD-BRAIN BARRIER? Neurosci Lett 101(1):46-50

Preston-Martin, S., J. M. Peters, M. C. Yu, D. H. Garabrant, and J. D. Bowman. 1988. MYELOGENOUS LEUKEMIA AND ELECTRIC BLANKET USE. Bioelectromagnetics 9(3):207-213

Quinlan, W. J., D. Petrondas, N. Lebda, S. Pettit, and S. M. Michaelson. 1985. NEUROENDOCRINE PARAMETERS IN THE RAT EXPOSED TO 60 Hz ELECTRIC FIELDS. Bioelectromagnetics 6(4):381-389

Ragan, H. A., R. L. Buschbom, R. D. Pipes, R. D. Phillips, and W. T. Kaune. 1983. HEMATOLOGIC AND SERUM CHEMISTRY STUDIES IN RATS EXPOSED TO 60 Hz ELECTRIC FIELDS. Bioelectromagnetics 4(1):79-90

Rannug, A., B. Holmberg, and K. H. Mild. 1990. STUDIES OF 50 MHZ ALTERNATING MAGNETIC FIELDS IN A RAT LIVER FOCI BIOASSAY (MEETING ABSTRACT). Bioelectromagnetics Society, 12th Annual Meeting, 10-14 June, San Antonio, TX, p. 17

Ravnborg, M., G. M. Knudsen, and M. Blinkenberg. 1990. NO EFFECT OF PULSED MAGNETIC STIMULATION ON THE BLOOD-BRAIN BARRIER IN RATS. Neuroscience 38(1):277-280

Reichmanis, M., F. S. Perry, A. A. Marino, and R. O. Becker. 1979. RELATION BETWEEN SUICIDE AND THE ELECTROMAGNETIC FIELD OF OVERHEAD POWER LINES. Physiol Chem Phys 11(5):395-403

Reiter, R. J. 1988. THE PINEAL GLAND, CELLULAR PROLIFERATION AND NEOPLASTIC GROWTH: AN HISTORICAL ACCOUNT. The Pineal Gland and Cancer. (D. Gupta, A. Attanasio, R. J. Reiter, eds.) Tubingen, FDR

Reiter, R. J., A. Lerchl, K. A. Stokkan, K. O. Nonaka, K. A. Howes, and B. A. Richardson. 1990. MAGNETIC FIELDS ALTER PINEAL SEROTONIN METABOLISM: CRITICAL EXPOSURE PARAMETERS (MEETING ABSTRACT). Annual Review of Research on Biological Effects of 50 and 60 Hz Electric and Magnetic Fields, 5-8 November 1990, Denver, CO, U.S. DOE, p. A30

Reiter, R. J., K. Yaga, L. C. Manchester, J. S. Sun, L. D. Chen, and M. Abdolsalami. 1992. PARAMETRIC AND MECHANISTIC STUDIES ON THE PERTURBATION OF THE CIRCADIAN MELATONIN RHYTHM BY MAGNETIC FIELD EXPOSURE (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 5

Renew, D. C., J. C. Male, and B. J. Maddock. 1990. POWER-FREQUENCY MAGNETIC FIELDS: MEASUREMENT AND EXPOSURE ASSESSMENT. Conference Internationale des Grands Reseaux Electriques a Haute Tension - CIGRE, August 26 - September 1, 1990, Paris, France, paper no. 36-105

Repacholi, M. H. 1990. CANCER FROM EXPOSURE TO 50/60 HZ ELECTRIC AND MAGNETIC FIELDS - A MAJOR SCIENTIFIC DEBATE. Australas Phys Eng Sci Med 13(1):4-17

Riley, V. 1981. PSYCHONEUROENDOCRINE INFLUENCES ON IMMUNOCOMPETENCE AND NEOPLASIA. Science 212:1100

Rius, C., Y. Alvarez-Rodriguez, and Y. Valladares. 1985. IN VITRO STUDIES OF THE EFFECT OF A PULSED ELECTROMAGNETIC FIELD ON NORMAL AND CANCER CELLS. Rev Esp Oncol 32(1):55-84

Rogers, W. R., R. J. Reiter, H. D. Smith, and L. Barlow-Walden. 1991. UNDER SOME CIRCUMSTANCES, COMBINED ELECTRIC AND MAGNETIC FIELD EXPOSURE REDUCES SERUM MELATONIN CONCENTRATION IN NONHUMAN PRIMATES (MEETING ABSTRACT). Annual Review of Research on Biological Effects of 50 and 60 Hz Electric and Magnetic Fields, 3-7 November 1991, Milwaukee, WI, U.S. DOE, p. A-26

Ross, S. M., R. P. Liburdy, T. F. Budinger, L. G. Salford, A. Brun, B. R. R. Persson, M. S. Roos, D. J. de Manincor, and K. M. Brennan. 1990. PERMEABILITY OF THE BLOOD-BRAIN BARRIER (BBB) OF THE RAT TO ALBUMIN IS NOT SIGNIFICANTLY ALTERED BY NUCLEAR MAGNETIC RESONANCE IMAGING (NMRI) FIELDS (MEETING ABSTRACT). Bioelectromagnetics Society, 12th Annual Meeting, 10-14 June, San Antonio, TX, p. 46

Rozengurtz, E., and S. A Mendoza. 1986. EARLY STIMULATION OF NA+ -H+ ANTIPORT, NA+ -K+ PUMP ACTIVITY, AND CA2+ FLUXES IN FIBROBLAST MITOGENESIS. Current Topics in Membranes, Vol 27, The Role of Membranes in Cell Growth and Differentiation, Orlando: Academic Press, p. 163

Rudolph, K., K. Krauchi, A. Wirz-Justice, and H. Feer. 1985. WEAK 50 Hz ELECTROMAGNETIC FIELDS ACTIVATE RAT OPEN FIELD BEHAVIOR. Physiol Behav 35(4):505-508

Sager, D. P. 1987. CURRENT FACTS ON PACEMAKER ELECTROMAGNETIC-INTERFERENCE AND THEIR APPLICATION TO CLINICAL CARE. Heart Lung 16 (2):211-221

Sahl, J. D., M. A. Kelsh, and S. Greenland. 1993. COHORT AND NESTED CASE-CONTROL STUDIES OF HEMATOPOIETIC CANCERS AND BRAIN CANCER AMONG ELECTRIC UTILITY WORKERS. Epidemiol 4 (2):104-114

Salzinger, K., S. Freimark, M. McCullough, D. Phillips, and L. Birenbaum. 1990. ALTERED OPERANT BEHAVIOR OF ADULT RATS AFTER PERINATAL EXPOSURE TO A 60 Hz ELECTROMAGNETIC FIELD. Bioelectromagnetics 11(2):105-116

Sasser, L. B., J. E. Morris, R. L. Buschbom, D. L. Miller, and L. E. Anderson. 1991. EFFECT OF 60 HZ ELECTRIC FIELDS ON PINEAL MELATONIN DURING VARIOUS TIMES OF THE DARK PERIOD (MEETING ABSTRACT). Annual Review of Research on Biological Effects of 50 and 60 Hz Electric and Magnetic Fields, 3-7 November 1991, Milwaukee, WI, U.S. DOE, p. A-24

Sasser, L. B., J. E. Morris, D. L. Miller, and L. E. Anderson. 1992. EFFECT OF ACUTE EXPOSURE TO MAGNETIC FIELDS ON PINEAL FUNCTION IN THE RAT (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 28

Saunders, R. D., and Z. J. Sienkiewicz. 1990. REVISED ADVICE ON LIMITS OF EXPOSURE OF PATIENTS AND VOLUNTEERS DURING CLINICAL MR DIAGNOSIS IN THE U.K. (MEETING ABSTRACT). Bioelectromagnetics Society, 12th Annual Meeting, 10-14 June, San Antonio, TX, p. 43

Savitz, D. A., H. Wachtel, F. A. Barnes, E. M. John, and J. G. Tvrdik. 1988. CASE-CONTROL STUDY OF CHILDHOOD CANCER AND EXPOSURE TO 60 Hz MAGNETIC FIELDS. Am J Epidemiol 128(1):21-38

Schaefer, H., and J. Silny. 1977. SUDDEN INFANT DEATH SYNDROME AND ELECTROMAGNETIC FIELDS: POINT OF VIEW. Med Klin 72(19):871-872

Schiffman, J. S., H. M. Lasch, M. D. Rollag, A. E. Flanders, G. C. Brainard, and D. L. Burk. 1992. EFFECT OF MAGNETIC RESONANCE IMAGING (MRI) ON PLASMA MELATONIN IN NORMAL HUMANS (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 74

Severson, R. K., R. G. Stevens, W. T. Kaune, D. B. Thomas, L. Heuser, S. Davis, and L. E. Sever. 1988. ACUTE NONLYMPHOCYTIC LEUKEMIA AND RESIDENTIAL EXPOSURE TO POWER FREQUENCY MAGNETIC FIELDS. Am J Epidemiol 128(1):10-20

Sikov, M. R., D. N. Rommereim, J. L. Beamer, R. L. Buschbom, W. T. Kaune, and R. D. Phillips. 1987. DEVELOPMENTAL STUDIES OF HANFORD MINIATURE SWINE EXPOSED TO 60 Hz ELECTRIC FIELDS. Bioelectromagnetics 8(3):229-242

Sikov, M. R., D. N. Rommereim, R. L. Buschbom, and L. E. Anderson. 1988. GROWTH OF PREGNANT RATS AND THEIR OFFSPRING DURING CHRONIC EXPOSURE AT MULTIPLE FIELD STRENGTHS OF 60 Hz ELECTRIC FIELDS (MEETING ABSTRACT). Bioelectromagnetics Society, 10th Annual Meeting, 19-24 June, Stamford, CT, p. 67

Speers, M. A., J. G. Dobbins, and V. S. Miller. 1988. OCCUPATIONAL EXPOSURES AND BRAIN CANCER MORTALITY: A PRELIMINARY STUDY OF EAST TEXAS RESIDENTS. Am J Ind Med 13(6):629-638

Spitz, M. R., and C. C. Johnson. 1985. NEUROBLASTOMA AND PATERNAL OCCUPATION. A CASE-CONTROL ANALYSIS. Am J Epidemiol 121(6):924-929

Stagg, R. B., P. T. Hardy, A. MacMurray, and W. R. Adey. 1992. ELECTRIC AND MAGNETIC FIELD INTERACTIONS WITH MICROSOMAL MEMBRANES: A NOVEL SYSTEM FOR STUDYING CALCIUM FLUX ACROSS MEMBRANES (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 12

Stern, F. B., R. A. Waxweiler, J. J. Beaumont, T. L. Shiu, R. A. Rinsky, R. D. Zumwalde, W. E. Halperin, P. J. Bierbaum, P. J. Landrigan, and W. E. Murray Jr. 1986. A CASE-CONTROL STUDY OF LEUKAEMIA AT A NAVAL NUCLEAR SHIPYARD. Am J Epidemiol 123(6):980-992

Stern, S., and V. G. Laties. 1990. MAGNETIC FIELDS AND BEHAVIOR (MEETING ABSTRACT). Annual Review of Research on Biological Effects of 50 and 60 Hz Electric and Magnetic Fields, 5-8 November 1990, Denver, CO, U.S. DOE, p. A25

Strumza, M. V. 1970. THE EFFECTS OF PROXIMITY TO HIGH VOLTAGE ELECTRICAL WIRES ON HUMAN HEALTH. RESULTS OF A MEDICAL INQUIRY. Arch Mal Prof 31(6):269-276

Stuchly, M. A., J. Ruddick, D. Villeneuve, K. Robinson, B. Reed, D. W. Lecuyer, K. Tan, and J. Wong. 1988. TERATOLOGICAL ASSESSMENT OF EXPOSURE TO TIME-VARYING MAGNETIC FIELD. Teratology 38(5):461-466

Stuchly, M. A., J. R. N. McLean, R. Burnett, M. Goddard, D. W. Lecuyer, and R. E. J. Mitchel. 1992. MODIFICATION OF TUMOR PROMOTION IN THE MOUSE SKIN BY EXPOSURE TO AN ALTERNATING MAGNETIC FIELD. Cancer Lett 65 (1):1-7

Sulpor, B. 1979. HIGH-VOLTAGE POWER LINES AND HUMAN HEALTH. Public Util Fortn 103(1):11-15

Surgalla, L. A. 1988. EFFECTS OF WEAK ELF FIELDS ON RATE OF CALCIUM TRANSPORT IN ISOLATED SARCOPLASMIC RETICULUM (MEETING ABSTRACT). Bioelectromagnetics Society, 10th Annual Meeting, 19-24 June, Stamford, CT, p. 66

Swerdlow, A. J. 1983. EPIDEMIOLOGY OF EYE CANCER IN ADULTS IN ENGLAND AND WALES, 1962-1977. Am J Epidemiol 118(2):294-300

Takahata, K., S. Nishijima, M. Ohgami, T. Okada, S. Nakagawa, and M. Yoshiwa. 1989. MAGNETIC SHIELDING BY A TUBULAR SUPERCONDUCTING WINDING IN PARALLEL AND TRANSVERSE FIELDS. IEEE Trans Magnetics 25(2):1889-1892

Tenforde, T. S., and R. P. Liburdy. 1988. MAGNETIC DEFORMATION OF PHOSPHOLIPID BILAYERS: EFFECTS ON LIPOSOME SHAPE AND SOLUTE PERMEABILITY AT PREPHASE TRANSITION TEMPERATURES. J Theor Biol 133(3):385-396

Thomas, J. R., J. Schrot, and A. Liboff. 1986a. INVESTIGATION OF POTENTIAL BEHAVIORAL EFFECTS OF EXPOSURE TO 60 HZ ELECTROMAGNETIC FIELDS. New York State Power Lines Project, Wadsworth Center for Laboratories and Research, Albany, NY; 76 pp.

Thomas, J. R., J. Schrot, and A. R. Liboff. 1986b. LOW-INTENSITY MAGNETIC FIELDS ALTER OPERANT BEHAVIOR IN RATS. Bioelectromagnetics 7(4):349-357

Thomas, T. L., P. D. Stolley, A. Stemhagen, E. T. H. Fontham, M. L. Bleecker, P. A. Stewart, and R. N. Hoover. 1987. BRAIN TUMOR MORTALITY RISK AMONG MEN WITH ELECTRICAL AND ELECTRONICS JOBS: A CASE-CONTROL STUDY. J Natl Cancer Inst 79(2):233-238

Thomson, R. A. E., S. M. Michaelson, and Q. A. Nguyen. 1988. INFLUENCE OF 60 Hz MAGNETIC FIELDS ON LEUKEMIA. Bioelectromagnetics 9(2):149-158

Tomenius, L. 1986. 50 Hz ELECTROMAGNETIC ENVIRONMENT AND THE INCIDENCE OF CHILDHOOD TUMORS IN STOCKHOLM COUNTY. Bioelectromagnetics 7(2):191-207

Tornqvist, S., B. Knave, A. Ahlbom, and T. Persson. 1991. INCIDENCE OF LEUKAEMIA AND BRAIN TUMOURS IN SOME 'ELECTRICAL OCCUPATIONS'. Br J Ind Med 48(9):597-603

Tornqvist, S., S. Norrell, A. Ahlbom, and B. Knave. 1986. CANCER IN THE ELECTRIC POWER INDUSTRY. Br J Ind Med 43:212-213

Tornqvist, S., T. Persson, B. Knave, and A. Ahlbom. 1987. CANCER INCIDENCE IN OCCUPATIONAL GROUPS EXPOSED TO LOW FREQUENCY ELECTROMAGNETIC FIELDS (MEETING ABSTRACT).

Biological Effects From Electric and Magnetic Fields, Air Ions and Ion Currents Associated with High Voltage Transmission Lines: Contractors Review. 1-4 November 1987, Kansas City, MO. U.S. DOE, Office of Energy Storage and Distribution, Washington, D.C. 20585, and Electric Power Res. Inst., Health Studies Program, Palo Alto, CA.

Tribukait, B., E. Cekan, and L-E. Paulsson. 1987. EFFECTS OF PULSED MAGNETIC FIELDS ON EMBRYONIC DEVELOPMENT IN MICE. Work with Display Units 86, International Scientific Conference on Work with Display Units, Stockholm, Sweden, May 12-15, 1986, B. Knave; P-G. Wideback, eds., Amsterdam: Elsevier Science Publishers B.V.: 129-134

Tsong, T. Y., and V. S. Markin. 1992. RESONANCE TRANSDUCTION OF LOW LEVEL ELECTRIC SIGNALS BY MEMBRANE PROTEINS: AN OSCILLATORY ACTIVATION BARRIER MODEL (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 48

Tuffet, S., B. Veyret, R. de Seze, and J-M. Moreau. 1992. DECREASE OF PROLIFERATION OF HUMAN TUMOR CELLS CAUSED BY PULSATING MAGNETIC FIELD (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 108

Tynes, T., and A. Andersen. 1990. ELECTROMAGNETIC FIELDS AND MALE BREAST CANCER. Lancet 336(8730):1596

Tynes, T., A. Andersen, and F. Langmark. 1992. INCIDENCE OF CANCER IN NORWEGIAN WORKERS POTENTIALLY EXPOSED TO ELECTROMAGNETIC FIELDS. Am J Epidemiol 136 (1):81-88

Tynes, T., H. Jynge, and A. I. Vistnes. 1993. A NESTED CASE-CONTROL STUDY OF LEUKAEMIA AND BRAIN TUMOURS IN NORWEGIAN RAILWAY WORKERS. Bioelectromagnetics Society, 15th Annual Meeting, 13-17 June, Los Angeles, CA, p. 85

Ubeda, A., M. A. Trillo, L. Chacon, M. A. Martinez, and J. Leal. 1992. SENSITIVITY OF CHICK EMBRYOS IN LATE GASTRULA TO A WEAK PULSED MAGNETIC FIELD (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 16

Udintsev, N. A., V. V. Ivanov, and V. V. Moroz. 1986. EFFECT OF LOW-FREQUENCY MAGNETIC FIELDS ON METABOLISM AND ITS REGULATION. Biological Effects of Electromagnetic Fields. Their Applications and Standardization. Collection of Scientific Papers. Pushchino, 1986. USSR Acad. of Sciences, Res. Center for Biological Studies, Inst. of Biological Physics: 94-108

Vagero, D., A. Ahlbom, R. Olin, and S. Sahlsten. 1985. CANCER MORBIDITY AMONG WORKERS IN THE TELECOMMUNICATIONS INDUSTRY. Br J Ind Med 42(3):191-195

Vagero, D., and R. Olin. 1983. INCIDENCE OF CANCER IN THE ELECTRONICS INDUSTRY: USING THE NEW SWEDISH CANCER ENVIRONMENT REGISTRY AS A SCREENING INSTRUMENT. Br J Ind Med 40:188-192

Valberg, P. A. 1992. A PUBLIC-HEALTH FRAMEWORK FOR ADDRESSING A LAYPERSON'S PERCEPTION OF EMF HEALTH RISKS (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 9-10

Wagner, P., and E. Mantiply. 1988. CHARACTERISTICS OF PROJECT HENHOUSE EXPOSURE SYSTEM (MEETING ABSTRACT). Bioelectromagnetics Society, 10th Annual Meeting, 19-24 June, Stamford, CT, p. 73

Walsh, M. L. 1988. THE ONTARIO HYDRO 60 Hz ELECTRIC AND MAGNETIC FIELD RISK ASSESSMENT PROGRAM (MEETING ABSTRACT). Bioelectromagnetics Society, 10th Annual Meeting, 19-24 June, Stamford, CT, p. 43

Weaver, J. C., and R. D. Astumian. 1989. THE RESPONSE OF LIVING CELLS TO VERY WEAK ELECTRIC FIELDS: THE THERMAL NOISE LIMIT. Science 247(4941):459-462

Wertheimer, N., and E. Leeper. 1979. ELECTRICAL WIRING CONFIGURATIONS AND CHILDHOOD CANCER. Am J Epidemiol 109(3):273-284

Wertheimer, N., and E. Leeper. 1982. ADULT CANCER RELATED TO ELECTRICAL WIRES NEAR THE HOME. Int J Epidemiol 11(4):345-355

Wertheimer, N., and E. Leeper. 1986. POSSIBLE EFFECTS OF ELECTRIC BLANKETS AND HEATED WATERBEDS ON FETAL DEVELOPMENT. Bioelectromagnetics 7(1):13-22

Wertheimer, N., and E. Leeper. 1989. FETAL LOSS ASSOCIATED WITH TWO SEASONAL SOURCES OF ELECTROMAGNETIC FIELD EXPOSURE. Am J Epidemiol 129(1):220-224

Whitfield, J. F., A. L. Boynton, R. H. Rixon, and T. Youdale. 1985. THE CONTROL OF CELL PROLIFERATION BY CALCIUM, CA2+-CALMODULIN, AND CYCLIC AMP. Control of Animal Cell Proliferation. Vol 1. (A. L. Boynton, H. L. Leffert, eds.) Academic Press, Orlando, p. 331

Wiklund, K., Einhorn, J., and G. Eklund. 1981. AN APPLICATION OF THE SWEDISH CANCER-ENVIRONMENT REGISTRY: LEUKAEMIA AMONG TELEPHONE OPERATORS AT THE TELECOMMUNICATIONS ADMINISTRATION IN SWEDEN. Int J Epidemiol 10(4):373-376

Wilkins, J. R., 3rd., and V. D. Hundley. 1990. PATERNAL OCCUPATIONAL EXPOSURE TO ELECTROMAGNETIC FIELDS AND NEUROBLASTOMA IN OFFSPRING. Am J Epidemiol 131(6):995-1008

Wilkins, J. R., 3rd, and R. A. Koutras. 1988. PATERNAL OCCUPATION AND BRAIN CANCER IN OFFSPRING: A MORTALITY-BASED CASE-CONTROL STUDY. Am J Ind Med 14(3):299-318

Wilson, B., L. B. Sasser, J. E. Morris, and L. E. Anderson. 1990. COMPARISON OF INTERMITTENT AND CONTINUOUS 60 Hz MAGNETIC FIELD EXPOSURE EFFECTS ON PINEAL GLAND FUNCTION IN THE RAT (MEETING ABSTRACT). Annual Review of Research on Biological Effects of 50 and 60 Hz Electric and Magnetic Fields, 5-8 November 1990, Denver, CO, U.S. DOE, p. A27

Wilson, B. W., and L. E. Anderson. 1989. ELF ELECTROMAGNETIC-FIELD EFFECTS ON THE PINEAL GLAND. Extremely Low Frequency Electromagnetic Fields: The Question of Cancer. B. W. Wilson, R. G. Stevens, L. E. Anderson, eds., Columbus, OH: Battelle Press, p. 159-186

Wilson, B. W., E. K. Chess, and L. E. Anderson. 1985. ALTERATIONS IN PINEAL TRYPTOPHAN METABOLISM IN RATS EXPOSED TO 60 HZ ELECTRIC FIELDS (MEETING ABSTRACT). Bioelectromagnetics Society, 7th Annual Meeting, 16-20 June, San Francisco, CA, E-5

Wilson, B. W., E. K. Chess, and L. E. Anderson. 1986. 60 Hz ELECTRIC-FIELD EFFECTS ON PINEAL MELATONIN RHYTHMS: TIME COURSE FOR ONSET AND RECOVERY. Bioelectromagnetics 7(2):239-242

Wilson, B. W., R. G. Stevens, and L. E. Anderson. 1989. NEUROENDOCRINE MEDIATED EFFECTS OF ELECTROMAGNETIC-FIELD EXPOSURE: POSSIBLE ROLE OF THE PINEAL GLAND. Life Sci 45(15): 1319-1332

Wilson, B. W., C. W. Wright, J. Morris, R. G. Stevens, and L. E. Anderson. 1988. DOMESTIC ELF FIELD EXPOSURE AND PINEAL GLAND FUNCTION (MEETING ABSTRACT). Bioelectromagnetics Society, 10th Annual Meeting, 19-24 June, Stamford, CT, p. 36

Wilson, B. W., C. W. Wright, J. E. Morris, L. E. Anderson, J. Latham, and A. Lewy. 1989. THE ELECTRIC BLANKET STUDY: CONCLUSIONS AND DESIGNS FOR FUTURE EXPERIMENTS (MEETING ABSTRACT). Annual Review of Research on Biological Effects of 50 and 60 Hz Electric and Magnetic Fields, 13-16 November 1989, Portland, OR, U.S. DOE, p. P-14

Wilson, M. A. 1990. EXTREMELY LOW FREQUENCY ELECTROMAGNETIC FIELD EFFECTS ON SHORT TERM MEMORY (MEETING ABSTRACT). Bioelectromagnetics Society, 12th Annual Meeting, 10-14 June, San Antonio, TX, p. 100

Wilson, M. A. 1991. INDUCED CURRENTS AND SHORT TERM MEMORY IN RATS (MEETING ABSTRACT). Bioelectromagnetics Society, 13th Annual Meeting, 23-27 June, Salt Lake City, UT p. 86

Winters, W. D. 1986. BIOLOGICAL FUNCTIONS OF IMMUNOLOGICALLY REACTIVE HUMAN AND CANINE CELLS INFLUENCED BY IN VITRO EXPOSURE TO 60 HZ ELECTRIC AND MAGNETIC FIELDS. New York State Power Lines Project, Wadsworth Center for Laboratories and Research, Albany, NY 12201; 105 pp.

Wright, W. E., J. M. Peters, and T. M. Mack. 1982. LEUKEMIA IN WORKERS EXPOSED TO ELECTRIC AND MAGNETIC FIELDS (LETTER TO EDITOR). Lancet 2(8308):1160-1161

Yao, G. D., M. Z. Luo, Y. D. Fu, and D. Q. Lu. 1992. EFFECTS OF 50 Hz ELECTRIC FIELDS ON MONOAMINE NEUROCHEMISTRY AND LEARNING BEHAVIOR IN RATS (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 118-119

Yellon, S. M. 1991. AN ACUTE 60 HZ MAGNETIC FIELD EXPOSURE SUPPRESSES THE NIGHTTIME MELATONIN RISE IN THE PINEAL AND CIRCULATION OF THE ADULT DJUNGARIAN HAMSTER (MEETING ABSTRACT). Annual Review of Research on Biological Effects of 50 and 60 Hz Electric and Magnetic Fields, 3-7 November 1991, Milwaukee, WI, U.S. DOE, p. A-25

Yong, Q. E., H. Chiang, K. Chen, G. D. Yoo, Z. Goo, and Y. D. Fu. 1992. A CASE-CONTROL STUDY OF SPONTANEOUS ABORTION AND ELECTRIC BLANKET USAGE DURING PREGNANCY (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 75

Youngson, J. H. A. M., A. D. Clayden, A. Myers, and R. A. Cartwright. 1991. A CASE/CONTROL STUDY OF ADULT HAEMATOLOGICAL MALIGNANCIES IN RELATION TO OVERHEAD POWERLINES. Br J Cancer 63(6):977-985

Zecca, L., V. Margonato, G. Esposti, V. Lucini, F. Fraschini, and P. Ferrario. 1989. BRAIN TRANSMITTERS IN RATS EXPOSED TO 50 HZ PULSED MAGNETIC FIELDS (MEETING ABSTRACT). J Bioelectr 8(2): 269; International Symposium in Honor of Luigi Galvani, 14-16, April, Bologna, Italy

Zhang, J., J. Adams, M. G. Morgan, and I. Nair. 1992. ESTIMATES OF EXPOSURE REDUCTION SUPPLY CURVES FOR SEVERAL DIFFERENT EFFECTS FUNCTIONS (MEETING ABSTRACT). First World Congress for Electricity and Magnetism in Biology and Medicine, 14-19 June, Lake Buena Vista, FL, p. 10

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