Assessment of Electromagnetic Fields at NASA Langley Research Center

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ABSTRACT
This report presents the results of an assessment of electromagnetic fields completed at NASA Langley Research Center as part of the Langley Aerospace Research Summer Scholars Program. This project was performed to determine levels of electromagnetic fields, determine the significance of the levels present, and determine a plan to reduce electromagnetic field exposure, if necessary. This report also describes the properties of electromagnetic fields and their interaction with humans. The results of three major occupational epidemiological studies is presented to determine risks posed to humans by EMF exposure. The data for this report came from peer-reviewed journal articles and government publications pertaining to the health effects of electromagnetic fields.

INTRODUCTION

Recently, a great deal of attention has been given to the possibility of detrimental health effects resulting from exposure to Extremely Low Frequency (ELF) Electromagnetic Fields (EMF). The first reports of the possibility of health effects resulting from EMF exposure originated in the 1960's from the Soviet Union. Researchers in the Soviet Union reported a number of varied health problems in persons working in high-voltage power switch yards. In 1977, the United States Department of Energy began researching EMF in response to concerns raised about the safety of utility workers. Wertheimer and Leeper performed a study in 1979 that showed a slightly increased risk of leukemia in children living near power lines in the Denver area. The results of the Wertheimer and Leeper study were not replicated. Since the Wertheimer and Leeper study, numerous epidemiological and biological studies have been performed to determine if EMF poses a significant threat to human health, but to date no concrete evidence has been presented to prove or disprove the possibility of detrimental health effects being caused by EMF.

Electromagnetic fields are virtually ubiquitous in our environment. NASA Langley Research Center has numerous varied work environments which correspond to varying levels of worker exposure to EMF. The purpose of this assessment is to present a review of existing studies of EMF health effects, present the results of a survey of EMF levels at LaRC, and present ideas to help in reducing EMF exposure at LaRC.

ELECTROMAGNETIC FIELD BASICS

Extremely Low Frequency (ELF) Electromagnetic Fields (EMF) are present wherever electricity is being generated, transmitted, or used. The electromagnetic spectrum is divided into ionizing and non-ionizing regions. Ionizing radiation includes gamma rays and X-rays. Non-ionizing radiation sources include visible light, infrared light, radio frequency and extremely low frequency. Non-ionizing and ionizing radiations are different from one another in how they are produced, how they propagate, how they react with matter, and how they produce biologic and health effects. Non-ionizing radiation is not strong enough to break chemical bonds in molecules and form ions. The higher the frequency (expressed in hertz), the shorter the distance between one wave and the next, and the greater the amount of energy in the field. A comparison between the wavelengths of a microwave oven and power lines illustrate this phenomenon. A power line operating at a frequency of 60 hertz has a wavelength of 3100 miles, while a microwave oven operating at 2450 megahertz (one megahertz = one million hertz) has a wavelength of 4.8 inches. Extremely low frequency electromagnetic fields include frequencies below 3000 hertz.

Magnetic fields are measured in units called gauss which express the magnetic flux density. A unit called the tesla has been agreed upon as an international standard, but the gauss is used more often by the general public. The material presented in this discussion will be given in gauss with distances expressed in inches and feet.

Conversion Between Magnetic Flux Density Units

1 gauss (G) = 1000 milligauss (mG)
1 milligauss (mG) = 0.1 micro tesla

In the United States, electrical power alternates at a rate of 60 cycles per second (hertz). This alternating current (AC) behaves differently than direct current (DC). Direct current flows directly from batteries to the device being powered while alternating current flows back and forth. The earth produces its own DC electrical energy through thunderstorms and currents deep within the earth's core. The DC magnetic field from the currents in the earth's core averages 500 milligauss (mG) which is higher than the magnetic field levels resulting from AC electrical power.

The earth's magnetic field has virtually no effect on human health because DC fields are not able to create currents in objects in the manner that AC fields from electrical power do. AC fields induce weak electric currents when they come into contact with humans, and have been the focus of research pertaining to human health effects resulting from EMF exposure.

Electromagnetic fields are made up of both electric and magnetic fields. Electric and magnetic fields behave very differently from one another even though they both result from the same source, electrical power. Electric fields are produced by voltage. When an appliance is plugged into an electrical outlet, an electric field is given off, even if the appliance is turned off. Magnetic fields are produced by current, so an appliance must be plugged in and turned on to give off a magnetic field. Electric fields can be shielded easily by conducting objects such as buildings. Magnetic fields can only be effectively shielded by using nonferromagnetic, high-conductive copper.

ELECTROMAGNETIC FIELD INTERACTION WITH HUMANS

Electromagnetic fields contact humans through the outer surface of the body. The fields then induce weak electric currents that flow through the body. Electromagnetic fields are not capable of penetrating cell membranes, they can only flow between cells. The human body has electrical activity of its own from the heart and brain. The currents from extremely low frequency electromagnetic fields are much weaker than the natural currents of the human body. The effects that electromagnetic fields have on the natural currents within the body are not well understood. The confusion lies in determining the exact mechanism by which electromagnetic fields interact with cells.

Electromagnetic fields are not capable of causing any tissue heating because the frequencies of ELF electromagnetic fields have frequencies 12 orders of magnitude less than very weak ionizing radiation.

Acute Physiological Effects

In 1991, research was performed at the Midwest Research Institute to determine the effects of EMF on human heart function. Healthy human volunteers were intermittently exposed to electric and magnetic fields. The results showed a statistically significant slowing of the heart rate. Exposure to the magnetic field (200 mG in strength) had a much greater effect than the electric field. Significant variation occurred in the responses of each individual. The variation in response was largely due to blood pressure and heart rate prior to exposure.

The researchers believe the change in heart rate was caused by interaction of the magnetic field with the nervous system which exercises control over heart rate and function. While the heart rate variations were statistically significant, they fall within the range of normal physiological variations.

Such effects would only be of concern if they have negative effects on human performance that might enhance the risk of accidents, produce a much stronger interaction with other stress factors, or give rise to more extreme effects in individuals with pre-existing heart problems. Currently, there is no evidence that the slight alteration in heart function caused by magnetic fields constitutes a health hazard.

The pineal gland acts as a biological timekeeper for the human body. In a process known as the circadian cycle the pineal gland secretes a hormone called melatonin. One of the major effects of EMF to be discovered is that high level EMF can suppress the normal nocturnal rise of melatonin in animals, and is believed to do the same in humans. In a study performed by Wilson et al. rats exposed to 60 hertz EMF had reduced levels of melatonin production which disrupted basic biological functions, behavior, and immune system response.

Several additional studies performed on pineal function show a significant effect to pineal gland output, but they can't be replicated for unknown reasons. The replication problems may be due to the sensitivity of pineal function. The pineal gland quickly responds to stress, light exposure, temperature, and diet. The individual response of each organism being studied makes it difficult to prove or disprove that a definite effect on pineal function is caused by EMF. Studies performed to determine if EMF disrupts the human biological timeclock have been inconclusive.

Recently, a great deal of attention has been focused on the role of melatonin in cancer, particularly breast cancer in women. Melatonin acts as a growth inhibitor of some types of cancer cells and improves the efficiency of the immune system which can indirectly help the body fight cancer cells. If EMF can inhibit melatonin production, it is possible that EMF can be thought of as a potential promoter of cancer cells, but this will be extremely difficult to prove because of the numerous variables that effect melatonin production

Effects on Cardiac Pacemakers

A number of studies performed in the early 1980's reported that electromagnetic interference can effect pacemaker function by altering pacemaker impulse formation, causing a reduction in pacemaker rate, or changing pacemaker operation from a need-based mode to a fixed-rate mode. In 1986 J.C. Griffin assessed what is required to put a pacemaker at risk from electromagnetic interference. In order for pacemaker function to be altered the user must have one of the few unipolar models that is affected by EMF, be completely dependent on the pacemaker at the time of interference, and experience the effects long enough to lose consciousness (at least 5 - 10 seconds). Only 10 - 20 percent of unipolar models are susceptible and only 20 - 25 percent of pacemaker users are totally dependent, so risk levels of cardiac malfunction from electromagnetic interference are relatively low. It has been suggested that standardization of pacemakers to resist electromagnetic interference would be the preferred mode of protection.

EPIDEMIOLOGICAL STUDIES

Epidemiology is the study of disease and its pattern of occurrence in human populations. Results of epidemiological studies are reported in terms of statistical association between various factors and disease. Epidemiology is an observational science, not an experimental science.

Principles of Epidemiology

Epidemiology is complicated by the difficulty of determining whether the results of a study indicate a true causal association because of the effects of other factors not included in the scope of the study known as confounding variables. A finding from a study is said to be statistically significant if researchers are 95 percent confident that an association exists. A statistically significant finding does not necessarily prove a causal association.

In most epidemiological studies pertaining to EMF researchers try to establish an association between the occurrence of a particular health related outcome and exposure to EMF. Two groups are assembled in an epidemiological study, the cases and the controls. The cases are the group with a particular disease (such as leukemia). The controls are the group who do not have the disease, but possess characteristics similar to those of the cases. This type of study is referred to as a case-control study. The next step is to estimate the exposure of the cases and controls to EMF. After exposure estimation, a calculation can be used to determine the relative risk (odds ratio).

$$\text{Relative Risk} = \frac{\text{Incidence rate among exposed}}{\text{Incidence rate among unexposed}}$$

The higher the value for the relative risk, the more likely it is that a particular factor (EMF) is capable of causing disease.

Review of Occupational Epidemiological Studies

Research into occupational exposure to EMF was launched in 1982 when Samuel Wilhelm, an epidemiologist at the Washington State Department of Social and Health Services found elevated leukemia rates in 10 of 11 occupations involving exposure to EMF. Numerous studies have been reported since this study, but no conclusive evidence has been found. Many studies conflict one another or find relative risk values so small they are inconclusive.

The conflicting nature of the studies may largely be due to the fact that most studies infer exposure assessment by job title instead of taking actual field measurements to determine worker exposure. This paper will review three recent occupational epidemiological studies. These studies were chosen because they have a large number of subjects, they are based on actual measurements of EMF in the workplace, they are well designed, and they have been thoroughly peer reviewed.

In 1994, Gilles Theriault published an occupational epidemiological study on EMF. The study focused on cancer risk among electricity workers at Ontario Hydro, Hydro-Quebec, and Electricite de France. The main priority of the study was to assess risk for leukemia, brain cancer, and skin melanoma, but risks for all other cancers were also assessed. Large numbers of people were included, an extended measurement campaign was performed, and a comprehensive assessment of exposure to other cancer risk factors was included. Assessment of exposure to other cancer risk factors included looking at past exposure to 47 toxic chemicals and cigarette smoke.

The research team looked at 223,292 utility workers. Exposure estimation was aided by workers wearing a personal exposure meter (dosimeter) for a full working week at various times of the year. A total of 10,330 days of worker exposure measurements were obtained. The data obtained from the worker measurements were combined with knowledge of present and historical working environments (dating back to 1945) encountered by the workers being studied to formulate an exposure estimation for each worker.

The median exposure to the workers was 31 mG-years. Workers whose exposure exceeded the median had a statistically significant relative risk of 3.2 at the 95 percent confidence interval for developing acute myeloid leukemia. No other associations were found for 29 other types of cancer when the data were analyzed. Theriault assessed the significance of his study by stating that even though he and his research team utilized all available means for exposure assessment and collected an immense amount of data, the results were imprecise because no clear dose-response was established.

Despite the fact that no concrete evidence to prove or disprove the theory that EMF can cause cancer, this study is the largest and most comprehensive study performed to date.

In 1993, Sahl, Kelsh, and Greenland studied 36,221 electrical utility workers at the Southern California Edison Company. The researchers assessed the risk of death in workers from leukemia, brain cancer, or lymphoma from 1960 to 1988. The researchers combined personal dosimetry with job histories to construct an exposure assessment for each employee.

Ten controls were used for each case of leukemia, brain cancer, and lymphoma The cohort (a group of persons who share a common experience within the same time period) was made up of all persons who worked at Southern California Edison for at least one year. The mean duration of employment was 13 years. No association between magnetic field exposure and deaths from leukemia, brain cancer, or lymphoma, as well as all other cancers was observed.

Matonoski et al. conducted a study of retired American Telephone and Telegraph lineworkers. A total of 124 leukemia cases were identified from the mortality records of AT&T. Three controls were selected for each case. Worker exposure was assessed through employment histories and actual EMF exposure monitoring of lineworkers and non-lineworkers under present working conditions. Each worker in the study was assigned a lifetime exposure score. For workers with a lifetime exposure score above the median, a doubling in leukemia risk was observed. Individuals who held jobs with intermittent peak exposures had a slightly higher risk of developing leukemia than workers with a constant exposure level. Cable splicers had the highest estimated mean exposure (4.3 mG), central office technicians had an intermediate mean exposure level of 2.5 mG, and installers had a mean exposure level of 1.7 mG which was the lowest.

Summary of Findings From Epidemiologic Data

While the studies presented in this report represent a significant improvement in design and methodology over past studies, they have provided no conclusive evidence that an effect from EMF exposure exists or does not exist. Theriault reported a slightly increased risk in acute myeloid leukemia, but was skeptical that his findings were inconclusive. Sahl et al. found no evidence of an association between EMF and cancer. Matanoski et al. reported an association between levels and duration of EMF exposure and cancer, but stated that

Problems will always exist in designing epidemiological studies pertaining to EMF due to the retrospective nature of EMF studies, confounding variables, and the difficulty in finding a truly unexposed population to act as controls. Interpretation of results will remain a problem until a dose-response relationship between EMF and detrimental health effects is demonstrated.

RESULTS OF EMF SURVEY

Research to assess exposure to EMF in occupations other than electrical power workers is still in its infancy. NASA-Langley Research Center has a diverse range of working environments and occupations. This survey was performed to characterize the magnetic field strengths in facilities at LaRC.

Methods

Measurements of magnetic field strengths were made at approximately 20 LaRC facilities. Magnetic fields were chosen over electric fields because magnetic fields are believed to be the more hazardous component of EMFs. Facilities were chosen after consulting with electrical safety personnel according to the level of electrical power consumption. Electrical substations and power lines were also included in the survey.

Area, point-in-time magnetic field measurements, often referred to as "spot" measurements were made during a walk through survey at each facility. Efforts were made to cover all areas of each facility. A significant level was considered to be above 1.0 mG. During the walk through, levels were continuously monitored while walking at a slow pace. When a significant reading registered on the display, it was recorded and the surroundings were assessed to determine the source of the field. Often, the facility coordinator or safety head would aid in the survey process by identifying areas that would be of potential concern in their facility. Every effort was made to perform surveys at a time when equipment pertinent to the task of each facilty was in operation.

Instrumentation

All measurements were made using a handheld ELF gaussmeter (Model PLM-100WB) manufactured by Macintyre Electronic Design Associates (Herndon, Virginia). The PLM-100WB is a general purpose, single axis AC gaussmeter which measures the root-mean-square (RMS) value of ELF magnetic fields. The survey was performed using the wideband mode where the meter covers the bandwidth of 12Hz to 50 kHz to account for the harmonics often present in ELF fields. The PLM-100WB has a probe (4.8" long x 0.8" diameter) separate from the unit to allow for determination of the orientation of the field. Measurements were made holding the probe approximately four feet above the floor, an arms length from the surveyor.

Results
The results of the survey will be presented by describing the data gathered at each facility.

1205 - Fatigue and Fracture Research Lab
Measurements taken throughout the first and second floor indicated background levels of less than 1 mG. The test area (Room 114) has various instrument test strength machines that produced levels ranging from 2 - 4 mG two feet away while the machines were in operation. The electrical panels in room 114 had levels of 3 - 4 mG at a distance of two feet.

1208 - Aircraft Noise Reduction Laboratory
The survey of this facility indicated all background levels to be less than 1 mG. Levels found were typical for any office environment. Elevated levels (under 20 mG) were measured in close proximity to computers, clocks, and desk lamps, but levels fell off to less than 1 mG at a distance of 1 foot from the source.

1212 (B,C,D) - Subsonic Tunnels
A measurement outside of room number 101 indicated a level of 1.3 mG. Investigation revealed that the measurement was taken below the intake for the air conditioning system. All other background levels in office areas were less than 1 mG. Room 139, an electrical panel room had readings ranging from 4 - 16 mG, but no work stations were in the area of these levels so worker exposure in this area is limited. Readings taken in the vicinity of the 14x22 foot Subsonic Tunnel while in operation ranged from 1.2 to 5.1 mG. The substation located in room 107 in 1212C had levels ranging from <1 mG to 3.5 mG. The high speed 7x10 foot Tunnel was not in operation at the time of the survey.

1220 - Air Lab, Simulation Research Facility, Transport Simulator, and Visual Landing Display System, Automation Technology
Measurements taken throughout the first and second floor indicated background levels of less than 1 mG with the exception of two areas in front of room 109 with electrical panels where levels ranged from 1.5 to 2.6 mG. The electromagnetics research area was not in operation at the time of the survey, but a large computer drive was in operation in this area. Six inches from the side of the drive, a level of 66 mG was recorded, but three feet from the drive the level dropped to 3.5 mG.

1227 - Substation DL
Measurements were taken at the fence surrounding the substation. Eight measurements were taken at this substation with a minimum of 0.3 mG and a maximum of 5.4 mG.

1233 - Stratton Road Substation
This substation receives power directly from the two sets of overhead power lines entering LaRC. Measurements taken at the four corners of the fence at the substation indicate levels of less than 1 mG. The power lines were measured at ground level, three feet from the ground, and six feet from the ground at the point where they entered the substation. The levels measured at six feet were the highest, ranging from 13.1 - 16.0 mG. The measurements taken at the edge of the right-of-way the power lines ranged from 1 to 2.5 mG.

1236 - National Transonic Facility
A survey of the facility was conducted while the tunnel was in operation. Readings were taken in the control room for the tunnel and in the area where the induction motors were located. The control room had numerous computers and video display terminals, but no significant (>1 mG) measurements were recorded. The induction motors had levels ranging from 24 - 72 mG.

1238 - Electronics Technology Lab
No readings greater than 1 mG were recorded other than measurements from within two feet of video display terminals.

1247 - Hypersonic Facilities Complex
Readings taken in office areas were less than 1 mG with one significant exception. In 1247B the electrical panels in room 113 had readings of up to 140 mG. An office (room 114) was located directly in front of room 113. Readings in room 113 along the wall which divided the two rooms ranged from 6 - 12 mG. Readings were also taken while the Scramjet Tunnel was in operation, but no significant levels were observed. Measurements taken in all other working areas were not significant. The basement has a number of motors and electrical panels that ranged from 2.3 to 14.8

1251 - Unitary Wind Tunnel
All measurements taken in office areas and control rooms were less than 1 mG. Readings in the area of tunnel drive motors and compressors range from 30 - 80 mG.

1253 - Substation S2
Readings were taken at the fence surrounding the substation. Levels ranged from less than 1 mG to 4.1 mG.

1268(A and B) - Computer Complex
Readings taken in the basement range from less than 1 mG to 175 mG. The reading of 175 mG came from the electrical intake for the building. Office areas had no significant background levels. In 1268 B, the mechanical equipment room (room 1205) had several dehumidifying units with levels ranging from 24 to 57 mG. Room 1215 had large computer drives with fields ranging from less than 1 mG to 5.5 mG. The substation located behind building 1268A had levels ranging from 2.5 to 7 mG. On the second floor of building 1268, room 2086 had large central computers with levels ranging from 1 mG to 6.7 mG. Several areas could not be surveyed because of building renovations. The penthouse had field levels ranging from 1.5 - 9.7 mG.

1270 - Printed Circuit Lab
Measurements ranged from 1.1 mG to 1.3 mG.

1271 - Engineering Support Lab
Measurements ranged from less than 1 mG to 1.7 mG.

1290 - Substation UWT
Fields from the power lines entering the substation measured 2.4 mG. Readings taken around the perimeter of the substation ranged from less than 1 mG to 26.2 mG.

Discussion
The results of the EMF surveys at LaRC indicate a wide range of values, but the majority of the surveys yielded values of less than 1 mG. The levels observed are several orders of magnitude lower than the exposure guidelines of 5000 and 10000 mG issued by the International Radiation Protection Association and the American Conference of Governmental Industrial Hygienists,

respectively. Furthermore, the levels observed correspond to the average residential exposure which ranges from 0.6 to 2.5 mG.

Magnetic field measurements have a high level of spatial variability. Field strengths often change by a factor of 100 over a distance of three feet from the source of the field. A great temporal variability also exists in magnetic field measurements. The spot measurements made in this survey reflect instantaneous magnetic field levels, so levels may be higher or lower from the recorded values depending upon the power consuming equipment in operation at that point in time. Every effort was made to survey facilities at a time when they were in full operation (i.e. wind tunnels and laboratories).

Background levels (away from power consuming equipment) were lower than 1 mG. The low background levels occur because with the exception of the power lines entering LaRC that run to the Stratton Road substation, all power distribution is accomplished through underground wiring and all indoor wiring is adequately grounded.

No accepted protocol exists for magnetic field measurements. Spot measurements are valid to identify background field levels and equipment which produces significant fields, but they can't account for the total exposure a worker receives as he or she moves to different locations. Personal dosimetry is the ideal method for exposure assessment because it allows continuous monitoring of exposure levels for long periods, but dosimeters are expensive and are inconvenient to wear for extended periods.

REGULATORY GUIDELINES FOR EMF EXPOSURE

The American Conference of Governmental Industrial Hygienists (ACGIH) and the International Commission on Non-ionizing Radiation Protection (IRPA/INIRC) have issued guidelines for 60 hertz EMF exposure. These guidelines were based on known effects of EMF such as nerve stimulation, and do not correspond to the small field strengths found in typical occupational environments. These guidelines do not distinguish "safe" from "unsafe" levels because it is not known what levels of EMF exposure (if any) constitute a health hazard.

The ACGIH Threshold Limit Values for 60 hertz EMF exposure state that occupational exposure should not exceed 10 G (10000 mG) and workers with cardiac pacemakers should not be exposed to levels in excess of 1 G (1000 mG). These levels represent the Ceiling Threshold Limit Value which states that this level should not be exceeded during any pert of the working exposure.

The IRPA/INIRC guidelines are as follows:

Occupational	
Whole working day	5 G (5000 mG)
Short Term (< 2 hours per day)	50 G (50000 mG)
For limbs	250 G (250000 mG)
General Public	
Up to 24 hours per day	1 G (1000 mG)
Few hours per day	10 G (10000 mG)

PRUDENT AVOIDANCE OF EMF EXPOSURE

Until the risks posed by EMF exposure are known, it is wise to attempt to reduce exposure to EMF. Prudent avoidance simply involves increasing the distance from a source of high fields or reducing the time spent in the fields. Prudent avoidance can be accomplished with little cost or inconvenience, and seems wiser than spending millions of dollars shielding magnetic field sources when there may not be a threat to human health

Ideas for prudent avoidance at LaRC include:

- Moving work stations away from electrical panels.
- Move small desktop clocks, fans, and all other appliances with small motors at least three feet from the work position.
- Workers should be advised to sit an arm's length (3 feet) away from their video display terminal (VDT) while it is in use. When the VDT is not in use it should be turned off. It is not necessary to re-boot to access data when the VDT is turned off.
- Work stations should not be in area surrounding drive motors, induction furnaces or other machinery with high electrical consumption
- All VDTs purchased should be shielded for magnetic field emissions

CONCLUSIONS

No biological or epidemiological studies have shown firm evidence of detrimental health effects resulting from exposure to extremely low frequency electromagnetic fields. Data from biological studies has been conflicting, and the studies that demonstrated evidence of significant effects have not been replicated. Epidemiological studies on EMF effects have suffered from inadequate exposure assessment and from problems in accounting for confounding variables.

The survey of magnetic field levels found that present levels are orders of magnitude lower than levels specified by current regulatory guidelines pertaining to EMF exposure.

At this point, the risks posed by occupational exposure to EMF are uncertain. The Department of Energy is coordinating the EMF RAPID (Electric and Magnetic Fields Research and Public Information Dissemination) Program in order to expand and accelerate ongoing EMF research efforts in the United States. The RAPID program is conducting research on possible health effects and addressing engineering-related issues such as exposure assessment and field management. The results of The RAPID program studies will provide adequate information for policy development at LaRC.

Until adequate information for policy development is available, a program for prudent avoidance will reduce EMF exposure with little cost or inconvenience.

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