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I. SUMMARY

In September 1993, the National Institute for Occupational Safety and Health (NIOSH) received a request for a health hazard evaluation at the Akron General Medical Center (AGMC) in Akron, Ohio. The request was submitted by the AGMC Medical Director due to concern that exposure to electric and magnetic fields may have contributed to a cluster of conotruncal birth defects in children of three female employees who worked either in the intensive care unit (ICU) or surgical post-anesthesia care unit (PACU). Measurements of electromagnetic fields (EMF) were made at the AGMC by NIOSH investigators on November 28, 29, and 30. The levels of extremely low frequency (ELF) and very low frequency (VLF) electric and magnetic fields ranged from 0.1 to 220 milligauss (mG) (ELF), 0.1 to 20 mG (VLF), 1.8 to 4.9 volts per meter (V/m) (ELF), and 0.5 to 2.0 V/m (VLF). All of these levels are below the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV)s for sub-radiofrequency electric and magnetic fields.

Based on the data collected in this evaluation, and comparison with current occupational criteria, NIOSH investigators concluded that no health hazard existed on the days of measurement from occupational exposure to ELF and VLF electric and magnetic fields in the ICU or PACU areas located on the third floor of the AGMC. Moreover, the measurements made in this evaluation suggest that exposure levels to such fields in the ICU and PACU areas are typical of other situations, such as small modern office environments and residences.

KEYWORDS: SIC 8062 (general medical and surgical hospitals), birth defects (conotruncal), ELF, VLF, EMF, health care workers

II. INTRODUCTION

In September 1993, the National Institute for Occupational Safety and Health (NIOSH) received a request for a health hazard evaluation (HHE) at the intensive care unit (ICU) and surgical post-anesthesia care unit (PACU) located on the third floor of the Akron General Medical Center (AGMC) in Akron, Ohio. The request was submitted by the Medical Director due to concern over a cluster of conotruncal birth defects (CBD) in children of three female employees and a possible link to electric and magnetic field exposures. The Medical Director asked NIOSH to determine if (a) the EMFs detected in the ICU and/or the PACU areas are within the normal ranges expected in a setting of this type, and (b) is there any difference between the levels found in these two areas and other floors of the hospital.

An epidemiological investigation of the birth defect cases had been conducted previously by the Birth Defects and Genetic Disease Branch at the Centers for Disease Control and Prevention (CDCP), Atlanta, Georgia, and a report was issued in October 1992.[1] The results of that investigation showed that the small cluster size restricted the findings and conclusions and that the cause of these defects would likely remain unknown. The report did state that "Although the occurrence of three conotruncal birth defects among approximately 33 births is much higher than expected, the occurrence could be a statistical artifact." On November 28, 29, and 30, 1993, NIOSH investigators conducted a site visit at AGMC to measure extremely low frequency (ELF) and very low frequency (VLF) electric and magnetic field levels on the third floor ICU and PACU locations.

III. MATERIALS AND METHODS

In performing this evaluation, NIOSH investigators made measurements: (1) in the ICU and PACU areas using walk-around techniques, (2) on a random sample of employees working in these areas using personnel monitors, and (3) at other locations where occupational exposure would occur, such as the second and fourth floors and near various medical electronic equipment and sources.

A. Instrumentation

Occupational exposure to various EMFs found at AGMC were evaluated using the following equipment:

* A Holaday Industries, Inc. model HI-3602 ELF sensor, connected to a HI-3600 survey meter, was used to document both the magnitude of ELF electric and magnetic fields and the electrical frequency (as well as the waveforms) produced by such fields. The electric field strength was measured in units of volts per meter (V/m) and the magnetic field strength was measured in units of milligauss (mG) over the frequency range from 30 to 800 hertz (Hz).

* A Holaday Industries, Inc. model HI-3627 3-axis ELF magnetic field meter was used to make isotropic measurements of the magnetic field in and around different workstations. The magnetic field is measured over the frequency region from 30 to 2000 hertz (Hz) and the dynamic range of the instrument is from 0.2 mG to 20 gauss (G).

* Selected measurements were made with the EMDEX II exposure system, developed by Enertech Consultants, under project sponsorship of the Electric Power Research Institute, Inc. The EMDEX II is a programmable data-acquisition meter which measures the orthogonal vector components of the magnetic field through its internal sensors. Measurements can be made in the instantaneous read or storage mode. The system was designed to measure, record, and analyze power frequency magnetic

fields in units of mG in the frequency region from 40 to 800 Hz. The meter has the capability of displaying magnetic field values in three different frequency bandwidths; broadband which measures magnetic fields from 40 to 800 Hz, harmonic that measures fields from 100 to 800 Hz, and the fundamental bandwidth which measures fields at 60 Hz.

* Average magnetic fields were documented by use of the AMEX-3D exposure meter. This small, lightweight three-axis magnetic field meter can be worn by a worker to monitor average magnetic fields exposure that are produced at small levels. The AMEX-3D stores an electrical charge, proportional to the time-integral of the magnetic field, which can then be read-out and converted into average magnetic field strength in units of mG over the frequency range from 35 to 1000 Hz.

* A Holaday Industries, Inc. model 3637 3-axis VLF magnetic field meter was used to make isotropic measurements of the magnetic field in and around different workstations. The magnetic field is measured over the frequency region from 2 kilohertz (kHz) to 400 kHz and the dynamic range of the instrument is from 6 mG to 400 G with special probe adapters.

* Frequency measurements were made with a Hewlett-Packard model 3561A dynamic signal analyzer connected to a Antenna Research Associates, Inc. model PLA-205/B passive loop antenna calibrated from 20 Hz to 5 Megahertz.

B. Measurement Approach

1. Field Measurements Made in ICU and PACU Areas

a. Unoccupied ICU Room

Floor plans for the ICU area were obtained from the Medical Center and a request was made, and approved, by the Medical Director to use an unoccupied ICU room in which to conduct field measurements. After observing where health care personnel worked while attending patients in adjacent occupied ICU rooms, the NIOSH investigators selected sampling locations to perform measurements in the unoccupied room. VLF and ELF electric and magnetic field measurements were made in the unoccupied ICU room at floor, four foot, and eight foot heights in each area. In order to determine the approximate magnitude of ELF and VLF electric and magnetic fields in the ICU room, measurements were made under a load and non-load condition. In the non-load condition, all electric equipment, including medical monitors, television sets, room lights, room clock, etc. were turned off. Under a load conditions, the ICU room would be operated as if a patient was in the room. If there was a difference in the loaded and unloaded conditions, the measurements taken at the various room locations would help define what the source was and the approximate exposure reduction magnitude possible. Not all of the electrical equipment in the unoccupied ICU room could be turned off since the control for two small ceiling lamps was not accessible. The ICU nurses helped NIOSH investigators develop a list of typical equipment that would be used in an ICU patient situation (load conditions), and then helped to obtain that equipment in order to perform the measurements. It was observed that the placement of electronic equipment in the ICU rooms was heavily influenced by the location of the patient's bed. Hence, EMF, that may originate in all directions from this equipment, would be higher nearer the bed and less further away from the bed. This observation suggests that EMF occupational exposure levels in the ICU area tends to be a function of the distance from the bed.

A number of ELF and VLF magnetic field measurements were obtained using the EMDEX II units and the Holaday meters in a walk-around monitoring mode by the NIOSH investigators. In this mode, the units were used to determine the range of magnetic field levels found in the ICU area. No attempt was made to record individual worker's time average exposure with these units when operating in this mode. When operated in this mode, the meters were held at waist height and slowly moved over a small area while walking at a slow pace. All measurements were made during the first two shifts.

Additional magnetic field data for this part of the evaluation was obtained from positioning AMEX-3D dosimeters within selected occupied ICU rooms located on the third floor of the Medical Center during first and second shift operations.

b. Field Measurements in Occupied PACU Area

Patients in the PACU area were neither separated into individual rooms, as was the situation in the ICU area, nor were the NIOSH investigators given an unoccupied PACU room in which to perform field measurements. In fact, during the evaluation there were as many as 15 to 25 patients in the restricted PACU area at one time. The presence of these patients (all who had just come out of the operating room), as well as medical staff, did not permit the same type of measurements to be performed in the PACU area as were performed in the ICU area. Instead electric and magnetic field measurements were made at locations where nursing and medical staff were observed using the electronic equipment. NIOSH investigators were informed that all equipment typically used in the area was present. Equipment in the PACU area was generally located on small tables positioned along the walls between patients. The distribution of occupational EMF exposure was more restricted since the electronic equipment was located on the back wall, exposure was not from all directions, and workers were somewhat removed from these sources. This observation suggests that occupational EMF exposure in the PACU area tends to be a function of the distance from the back wall and not the bed. The NIOSH investigators also observed that on the days of measurement the number of electrical medical devices used per patient was higher in the ICU area than in the PACU area. In addition, it was observed that the ICU nursing staff spends more time nearer the electrical devices than in the PACU area. This is probably due to the fact that patients in the PACU area, who are recovering from operations, may not require as much sophisticated electronic equipment as patients in the ICU who are undergoing extensive traumatic conditions.

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2. Personal Field Measurements in the ICU and PACU Areas

EMDEX dosimeters were worn either around the waist or neck by six randomly selected ICU and three randomly selected PACU workers for portions of their workday. The meters were set at a 3.0 second data collection interval.

3. Measurements Made at Other Locations

A number of measurements were obtained using the EMDEX II units and the Holaday meters in a walk-around monitoring mode by NIOSH investigators. In this mode, the units were used to determine the lowest and highest levels found on the second and fourth floors to (a) insure that magnetic fields were not being measured on the third floor from sources on other floors, and (b) determine the EMF levels on other floors.

IV. EVALUATION CRITERIA

At the present time, there are no Occupational Safety and Health (OSHA) or NIOSH exposure criteria for sub-radiofrequency fields. The American Conference of Governmental Industrial Hygienists (ACGIH) has published Threshold Limit Values (TLVs) for sub-radiofrequency electric and magnetic fields.[2] The TLV for magnetic field (B) requires "routine occupational exposure should not exceed:

$$B_{TLV} \text{ (in mT)} = 60/f$$

where mT is millitesla and f is the frequency in Hz." For example, 12 kHz magnetic field limit would be 5 mT or 50 mG. Conversely, the electric field (E) TLV states "occupational exposures should not exceed a field strength of 25 kilovolts per meter (kV/m) from 0 to 100 Hz. For frequencies in the range of 100 Hz to 4 kHz, the TLV value is given by:

$$E_{TLV} \text{ (in V/m)} = 2.5 \times 10^6/f$$

where f is the frequency in Hz. A ceiling value of 625 V/m is the ceiling value for frequencies from 4,000 to 30,000 Hz. The basis of the ELF electric field TLV is to minimize occupational hazards arising from spark sidecharge and contact current situations. The magnetic field TLV addresses induction of magnetophosphenes (a visual sensation of white light) in the visual system and production of induced currents in the body. Prevention of cancer is not a basis for either of these TLVs because exposure has not been conclusively linked to cancer. Moreover no criteria for ELF exposure has been developed for conotruncal birth defects.

It should be recognized that the ACGIH has recently proposed new TLVs for the sub-radiofrequency region that will alter the above levels. The proposed TLV for magnetic flux density (B_{TLV}) in the sub-radiofrequency region recommends the use of the same magnetic field equation TLV but has adopted a ceiling value of 1 mT (10 G) from 1 to 300 Hz and a ceiling value of 0.2 mT (2 G) from 300 to 30,000 Hz. The proposed TLV for electric field strength has now become a ceiling value.

V. RESULTS

A. Field Measurements in the ICU Area

The ELF and VLF measurement locations in the unoccupied ICU room were chosen as typical measurement positions based on NIOSH observations and interviews with health care workers in other occupied ICU rooms. Measurements in the ICU area were designed to determine the difference between the measurements made with electrical equipment on (loaded conditions) and the measurements made with electrical equipment turned off (unloaded conditions). The only meaningful difference in either the ELF or VLF magnetic field levels measured in this manner occurred at the ceiling positions near lights which could not be turned off by the NIOSH investigators. The floor and waist positions produced minimal levels of both ELF and VLF magnetic fields compared to the levels measured at the ceiling locations. All levels are below the ACGIH TLV levels for ELF fields of 10,000 mG.

ELF electric field levels in the room ranged from 3.1 to 3.3 V/m, while VLF electric fields did not exceed 1 V/m. These levels are all below the ELF and VLF electric field TLVs. The electric field measurements made in the hallway immediately outside the ICU room were of the same magnitude as in the room.

B. AMEX Dosimeter Measurements in the PACU Area

AMEX-3D dosimeters were placed at 13 different locations within the entire ICU area for about two to three hours. The locations were chosen to give representative occupational magnetic field exposure levels to a number of situations. Measurements were made in the ICU rooms, near the nurse workstations, in the hallway outside the ICU area, and near computer workstations outside the patient rooms. The exposures from these 13 dosimeters ranged from 0.59 to 30 mG. The three highest levels measured were 30, 10.7, and 5.7 mG and all three dosimeters were located near either computers or a battery charging system. One of the remaining ten dosimeters was located in the outside hallway and the other nine were located either in or next to patient rooms. These ten dosimeters gave magnetic field levels that ranged from 0.59 to 1.42 mG.

C. Walk-around Measurements in the PACU Area

Measurements of electric and magnetic fields made in the PACU area using a walk-around mode technique at selected sites where workers were located, ranged from 1.9 to 4.9 V/m and from 0.1 to 24 mG in the ELF region and from 0.9 to 2 V/m and 0.1 to 20 mG in the VLF region.

D. Personnel Measurements Made in ICU and PACU Areas

Five EMDEX meters, set at a 3.0 second sampling time, were worn by randomly selected personnel in the ICU area for about two hours. These meters were worn either around the waist or neck by employees during performance of their work tasks. The data collected by the EMDEX meters differentiates between broadband, fundamental, and harmonic bandwidths. The average broadband ELF magnetic field levels measured in the ICUs with the EMDEX meters ranged from 1.05 to 1.44 mG. The maximum level recorded in the ICU area with any EMDEX meter was 25.1 mG. The levels of magnetic field measured was much higher in the fundamental bandwidth than the harmonic bandwidth, which suggests dominant 60 Hz exposure.

Three EMDEX meters, set at a three second sampling time, were also used to collect magnetic field results in the PACU area. The average magnetic fields measured in the PACU area with the EMDEX meters ranged from 1.04 to 1.17 mG over approximately a one hour exposure period. The maximum level recorded in the PACU area with any EMDEX meter was 28.7 mG, which was similar to the maximum recorded in the ICU area. As with the ICU area, the data collected in the PACU area also suggests a dominant 60 Hz exposure pattern. The intensity and temporal nature of the levels of magnetic fields recorded with the EMDEX meters for both the ICU and PACU areas were quite similar.

It was observed that in both the ICU and PACU area the standard deviations associated with the average value of the magnetic field were small in magnitude which suggests that there is minimal variance in magnitude fields with time as measured on the days of evaluation. This observation is consistent with the reported low average magnetic field levels documented in both areas.

E. Measurements Made at Other Locations

Using walk-around techniques, NIOSH investigators measured ELF and VLF magnetic field levels on the second and fourth floors, directly under the ICU and PACU areas, as high as 5 mG (ELF) and 1 mG (VLF). This finding, as well as the data collected in the ICU area near the ceiling and floor positions, suggests (a) whatever magnetic fields produced on the third floor were from sources and distribution systems on the third floor, and not from sources located on other floors, and (b) EMF levels on other patient floors are low.

It is noted that there are few EMF exposure sources on other patient floors so that the difference in magnetic field levels shown in Table 1 is deceiving when compared to the ICU or PACU areas. Almost all of the levels obtained from the walk-around mode were enhanced due to the closeness of various electronic sources, some which are listed in Table 2, in the ICU and PACU areas. The NIOSH investigators believe that the most important numbers shown in Table 1 are those associated with the EMDEX meters since they indicate personnel exposure. Those levels are very low, 0.3 to 1.4 mG, and indicate that the time of exposure is an important controlling factor. Further support for the apparent disparity in measured levels is found from the levels measured by the AMEX meters. As explained earlier, some of the AMEX meters were placed close to the sources and gave levels ranging from 0.6 to 30 mG. Therefore, the magnetic field levels measured on various patient floors are not all that different.

The above discussions leads the NIOSH investigators to conclude, based on walk-around measurements, that a wide range of medical and non-medical EMF-producing sources exist at AGMC. These sources, some which are shown in Table 2, can cause localized EMF exposure at close distances. These sources are:

electric hole puncher	various electric lamps
wall and desk clocks	AM/FM radios
televisions	video display units
battery chargers	coffee pots
electric typewriters	refrigerators
water dispensers	photocopy machines
power strips	patient heaters
strip chart recorders	fax machines
intercoms	defibulators

VI. DISCUSSION AND CONCLUSIONS

As a result of the measurements and observations made by the NIOSH investigators during this evaluation the following conclusions are made:

A. All levels of ELF and VLF electric and magnetic fields measured at AGMC in the ICU and PACU areas were within the range of exposure levels typically found in small office and residential settings previously reported by NIOSH and others, and are below current occupational exposure criteria. It should be noted, however, that research suggests that health effects related to ELF fields are linked to many variables, of which field strength is only one.

B. Inferences about the etiology of CBD can not be made based on the EMF measurements made at AGMC for at least three reasons: (a) there is no scientific data that implies CBD are related to EMF field strength levels in the 0.1 to 30,000 Hz frequency region, (b) at the present time NIOSH does not know if EMF fields cause any known health effects, much less CBD, and (c) it is not yet known what EMF exposure parameters should be used, if any, to document EMF health effects.

C. Many of the electrical sources found at AGMC during this evaluation may be considered essential to the modern health care environment. Some of the sources, however, are considered "non-essential" and their presence could be re-evaluated if there is concern about overall exposure to ELF. While it may be difficult to entirely eliminate all of this exposure to workers, awareness of these possible exposure levels may motivate employees and management to develop alternative approaches of controlling exposures, such as reducing time of exposure, shielding sources, and/or increasing distances from sources.

D. Measurements made on other floors at AGMC suggest that there is little difference between EMF levels on different floors over the days of evaluation. Moreover, whatever magnetic field levels exist, they appear to originate on the third floor and not from other floors.

VII. REFERENCES

1. CDCP [1992]. EPI-AID trip report: cluster of conotruncal heart defects at Akron, Ohio (EPI-92-96) from Margaret Watkins, Birth Defects and Genetic Diseases Branch, Division of Birth Defects and Developmental Disabilities, National Center for Environmental Health, October 23, 1992.

2. ACGIH [1992]. Threshold limit values for chemical substances and physical agents and biological exposure indices for 1993-1994. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

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Table 1

Summary of Ranges from ELF and VLF Electric (V/m) and Magnetic (mG) Field Levels as a Function of Type of Measurement

Akron General Medical Center
HETA 93-1120
November 28-30, 1993

Measurement Type	ELF		VLF*	
	V/m	mG	V/m	mG
Fixed Locations				
ICU Area	3.1 - 3.3	0.2 - 220	0.5 - 1	0.1 - 20
Walk-around				
ICU Area	1.8 - 3.1	0.1 - 33	1.0	0.3 - 35
PACU Area	1.9 - 4.9	0.1 - 24	0.9 - 2	0.2 - 20
2nd Floor	1.9 - 2.0	0.1 - 5	1.1	0.1 - 1
4th Floor	1.8 - 2.1	0.2 - 3	1.2	0.3 - 1
AMEX Meters				
ICU Area	-	0.59 - 30	-	-
EMDEX Meters				
ICU Area				
Fundamental	-	0.92 - 1.29	-	-
Harmonics	-	0.39 - 0.6	-	-
Broadband	-	1.05 - 1.44	-	-
PACU Area				
Fundamental	-	0.87 - 1.04	-	-
Harmonics	-	0.30 - 0.43	-	-
Broadband	-	1.04 - 1.17	-	-

* The Holaday Model 3637 VLF magnetic field meter measures from 2 to 400 kHz.

Table 2

Summary of Maximum ELF and VLF Magnetic Field (mg) Level Measurements on Selected ICU and PACU Sources

Akron General Medical Center
HETA 93-1120
November 28-30, 1993

Source/Location	Region	Measurements Made at		
		Contact[a]	Arm[b]	Chest[c]
Puritan Bennett 7200a Microprocessor Ventilator	ELF VLF	37 100		4 2
Kendall Sequential Compression Device Model 53	ELF VLF	524 20		 4
Baxter Flow Guard 6300 Volumetric Infusion Pump	ELF VLF	320 120	9	2 3
Warm Touch Patient Bed Heater	ELF	350		6
Critikon-Dinamap 1846X Vital Sign Monitor	ELF VLF	24 40	4 20	3
Hewlett-Packard 78353B Patient Monitor	ELF VLF	71 1000	3 35	
Room TV Set	ELF VLF	45 240		2 4

(a) Contact with equipment.
(b) "ARM" measurement made at 12 inches.
(c) "CHEST" measurement made at 24 inches.