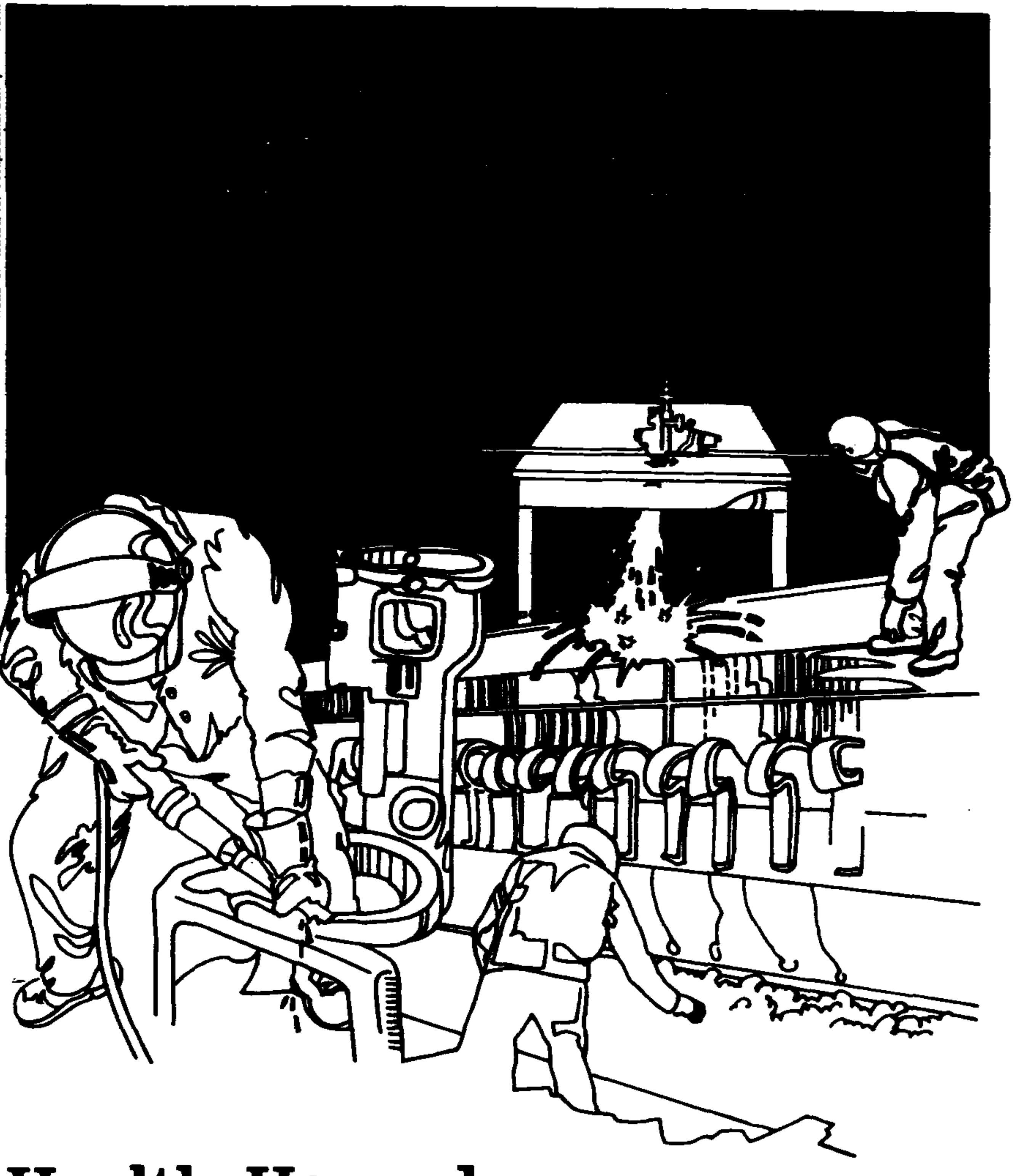
U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES ■ Public Health Service
Centers for Disease Control ● National Institute for Occupational Safety and Health



Health Hazard Evaluation Report

HETA 87-329-1898
FERMILAB
BATAVIA, ILLINOIS

PREFACE

The Hazard Evaluations and Technical Assistance Branch of NIOSH conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

The Hazard Evaluations and Technical Assistance Branch also provides, upon request, medical, nursing, and industrial hygiene technical and consultative assistance (TA) to Federal, state, and local agencies; labor; industry and other groups or individuals to control occupational health hazards and to prevent related trauma and disease.

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FERMILAB
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I. SUMMARY

On June 17, 1987, the National Institute for Occupational Safety and Health (NIOSH) received a request from the Fermi National Accelerator Laboratory (Fermilab) for assistance in assessing worker exposure to radiofrequency (RF) radiation produced by the atomic particle accelerator system.

On August 28, 1987, NIOSH investigators conducted a walk through familarization tour of the facility. On January 19-21, 1988, NIOSH personnel returned to Fermilab and conducted RF and static magnetic field strength measurements. Measurements of RF radiation were made at selected equipment and/or work areas in the Linac, Booster, and Main Ring areas. The Linac area was selected due to the larger number of workers potentially exposed and the Main Ring was chosen since it had never been assessed. In addition measurements were recorded during a simulated general public guided tour and also at an end-users experimental station set up. Finally, measurements were made at locations along the row of offices in the Linac walkway. Static magnetic field measurements were obtained at selected areas within the Linac, bubble chamber, and end-user experimental station.

No measurement for RF radiation exceeded exposure limits recommended by the American National Standard Institute C-95.1 standard. Static magnetic fields were present in the Linac and Bubble Chamber areas. These magnetic field levels exceeded the recently proposed ACGIH TLV at some locations.

Based on the results of this investigation and existing evaluation criteria, occupational exposure to radiofrequency radiation did not represent a health hazard at the time of this evaluation. While the exposure potential exists, shielding, control measures, and awareness of the potential RF hazard by the workers helps greatly to limit occupational exposure. Due to the lack of national recognized standards for static magnetic field exposure, it is recommended that Fermilab document such exposures for possible future analysis. Recommendations are made in Section VIII for additional control measures to protect the worker.

KEYWORDS: SIC 8922 (Noncommercial scientific organization) RF radiation, magnetic fields, particle accelerator

II. INTRODUCTION

On June 17, 1987, NIOSH received a request from the Fermi National Accelerator Laboratory (Fermilab) for assistance in assessing worker exposure to radiofrequency (RF) radiation from the atomic particle accelerator systems. A preliminary visit was made to Fermilab on August 28, 1987 by NIOSH personnel to tour the facility and observe operations and equipment in use at the laboratory. On January 19-21, 1988 NIOSH investigators returned to this facility and collected RF and static magnetic field density measurements at selected sites throughout the facility.

III. BACKGROUND

Fermilab employs high power RF amplifiers to accelerate protons and anti-protons to energies approaching 1 Tera (10^{12}) electron volt (TeV). At this energy level this makes Fermilab one of the world's most powerful accelerators. Research performed at Fermilab is known as "high energy physics." The purpose of such research is to explore the basic structure of matter. No product is produced at the accelerator other than knowledge gained by the research.

Fermilab is operated by the Universities Research Association Inc. (URA) a consortium of 56 major research-oriented universities. URA operates the laboratory under a contract with the Department of Energy (DOE). The laboratory is located on 6800 acres near Batavia, Illinois and employs about 2200 full time workers of which 400 are scientists and engineers. Figure 1 shows the overall layout of the area. The large circle in the figure is the main accelerator. Three experimental lines extend at a tangent from the accelerator. The 16-story Wilson Hall is located at the base of the experimental lines and serves as headquarters for the entire operation.

At Fermilab the method used to accelerate protons occurs generally in the following manner:

1. Electrons are added to hydrogen atoms in an ion source located in a Cockcroft Walton generator. The resulting ions, which are protons with two attached electrons, emerge from the high voltage accelerator with an energy of 750,000 eV. Since these ions, and later protons, have electric charge they can be controlled by the use of a magnetic field. This magnetic field can be electronically altered so as to keep the particles on a desired path as they travel near the speed of light.

2. The ions enter the linear accelerator (linac), approximately 500 feet in length, where they are accelerated to an energy near 200 MeV. The linac is designed to produce an electrical equivalent "surf wave" for the ions to ride as they are made to accelerate.

3. The ions are then injected into a booster accelerator, a circular device located below the ground. This accelerator goes through its cycle 15 times a second (ie, 15 Hz). During this phase the ions are stripped of their electrons, leaving protons. The protons are then increased in energy to 8 GeV.

4. The protons are next injected from the booster into the main accelerator. This accelerator is about 6600 feet in diameter and almost four miles in circumference. The main accelerator has two rings of magnets which are used to provide further acceleration depending upon whether the system is operated as a fixed target or in a collider mode.

It should be noted that in addition to potential RF and magnetic field exposures, there is also the possibility for ionizing radiation exposure. In fact, the only limitation on work practices placed on anyone at the facility is established on ionizing radiational factors, and not RF exposure. The use of waveguides at Fermilab greatly reduces occupational exposure to RF. In addition, the shielding and potential for ionizing radiation exposure restricts access to locations where RF levels are high. As a result, occupational exposure is generally limited to RF leakage issues, especially for servicing and maintenance personnel. Finally, it is difficult to get close to the accelerating particles and the resulting radiation fields due to presence of interlocks and security devices.

IV. EVALUATION CRITERIA

A. Environmental Criteria

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for assessment of a number of chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects if their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or a hypersensitivity (allergy).

In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the evaluation criteria. These combined effects are often not considered in the evaluation criteria. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus potentially increase the overall exposure. Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available.

The primary sources of environmental evaluation criteria for the workplace are: 1) NIOSH Criteria Documents and recommended exposure limits (RELs), 2) the American Conference of Governmental Industrial Hygienist's (ACGIH) Threshold Limit Value (TLV's), 3) the U.S. Department of Labor (OSHA) permissible exposure limits (PELs), 4) applicable American National Standard Institute (ANSI) documents, and 5) current governmental research and articles found in peer-reviewed publications. Often, the NIOSH and ANSI recommendations and ACGIH TLV's are lower than the corresponding OSHA standards. NIOSH, ANSI, and ACGIH TLV's usually are based on more recent information than are the OSHA standards. In evaluating the exposure levels and the recommendations for reducing these levels found in this report, it should be noted that industry is legally required to meet those levels specified by an OSHA standard.

B. RF Radiation Occupational Exposure Limits

The Occupational Safety and Health Administration (OSHA) has a standard for RF exposure in the frequency range of 10 to 100,000 MHz.[1] According to 29CFR1910.97, workers must not be exposed to a power density level exceeding 10 mW/cm^2. This is equivalent to a electric field (E-field) intensity strength of 40,000 volts squared per meter squared (V^2/m^2) and a magnetic field (H-field) intensity strength of 0.25 amperes squared per meter squared (A^2/m^2) averaged over any 0.1 hour period. The standard was taken from ANSI C-95.1 in 1966.[2] The ANSI standard was revised in 1982 and the exposure guidelines were reduced. In this standard there are different field strength values for selected frequency regions, but in the frequency range from 10 to 300 MHz, the guideline is 4000 V^2/m^2 for the E-field and 0.025 A^2/m^2 for the H-field. These exposures are also averaged over a 0.1 hour period.

C. Static Magnetic Field Occupational Exposure Limits

There have been no official occupational health limits set for static magnetic fields. In 1971, the Stanford Linear Accelerator Center proposed values of 2000 to 20,000 Gauss, depending on time and exposure area of body, for a upper limit based on lack of complaints.[3] In 1979, the Department of Energy, based on known biological effects that had been reported, established more conservative limits of up to 20,000 Gauss. The only other limit for this type of exposure has been proposed by ACGIH in 1987.

Their draft standard recommends that "Routine occupational exposures should not exceed 600 Gauss whole body or 6000 Gauss to the extremities on a daily, time-weighted average basis. A flux density of 20,000 Gauss is recommended as a ceiling value......"(4)

D. Biological Effects of radiofrequency radiation [5,6]

Absorption of RF energy can adversely affect a worker's health since human and animal studies indicate that this type of radiation can cause harmful biological effects due to excessive heating of body tissues. Absorption of RF energy may also result in "nonthermal" effects on cells or tissues, which occur without a measurable increase in tissue or body temperature. Such effects are reported to occur from exposure to RF energy at levels lower than those sufficient to cause thermal effects. RF radiation can penetrate the body and cause heating of internal tissues. The body's heat sensors are located in the skin and do not readily sense heating deep within the body. Therefore, workers may absorb large amounts of radiation without being immediately aware of the presence of such energy. There have been reports that personnel exposed to RF fields from radar equipment, RF heaters and sealers, and radio/TV towers have experienced a warming sensation some time after being exposed.

Exposure of pregnant animals to thermal levels of RF energy can cause birth defects and kill the fetus. RF exposures have also been associated with human miscarriages, irregular menstrual cycles, and decreased location in nursing mothers.

Testicular damage and partial to total sterililty in male animals has been produced at high intensities of RF. Sterility, decreased sperm production, decreased sperm motility, and decreased libido have been reported in workers exposed to RF. RF induced heating can damage the brain, spinal cord, muscles, blood, liver, kidneys, and skin. Such effects have generally been attributed to cellular damage resulting from excessive temperature increases.

There is little supportable evidence that RF radiation can cause cancer. However, recent evidence suggests that it may act as a cancer promoter in animals. In addition, there is no consensus on the potential hazard of low-level chronic RF radiation exposure, but biological changes definitely occur during or following relatively low intensity exposure.

There is general agreement that the incidence and severity of RF biological effects are related to the magnitude of radiation power absorbed by the body. This absorption depends strongly upon the frequency and intensity of the radiation, the size and shape of the exposed worker, and the worker's orientation in the radiation field. The human body absorbs maximally in the frequency range of 30-300 Megahertz (MHz). Outside this range, much less energy is absorbed from the field.

E. Biological Effects of Static Magnetic Fields [7,8]

In general there are two conditions for magnetic field exposures which need to be understood. Exposures can occur either from a steady or time-varying field exposure. In a steady magnetic field, the flux does not change with time and will not cause current to flow in a fixed object. In a time-varying field the magnetic flux passing through a surface changes with time and can induce a electrical current flow in conductive objects. Both types of fields create different biological effects.

Exposure to static magnetic fields has been linked to slight increases in blood pressures, alternation in operation of artificial cardiac pacemakers, movement of implanted metal objects, rotation of sickle cells, influencing length of circadian cycle, and attractiveness of metal objects. Many scientists believe that the effect of static magnetic fields are very subtle and may not represent a particularly hazardous exposure.

Some of the effects of exposure to time-varying magnetic fields are recognized at this time, particularly in the frequency range at 60 Hz and its harmonics. An occupational time-varying magnetic field can induce current in the body equivalent in magnitude to that caused by the normal activity of the heart and brain. In addition, published studies show that time-varying magnetic fields can produce flickers of visible light in the eye, as well as affect the efflux of calcium ions from selected animal membranes. Several epidemiological studies have suggested that exposure to time-varying magnetic fields could be carcinogenic in humans. This particular issue has not been completely studied and more data is necessary.

Very little epidemiological work has been performed in steady magnetic fields, and what has been done for time-varying magnetic fields has been contradictory. It is quite obvious that more work is necessary and that until the work has been completed exposure guidelines are at best incomplete.

V. METHODS

NIOSH investigators decided to monitor only certain key selected areas of Fermilab for static magnetic and radiofrequency fields due to the size and scope of the facility. Since Fermilab , on two previous dates had attempted to characterize the RF fields, NIOSH investigators utilized the same basic approach for this study.

The first step taken was to verify the RF frequency values reported to us on the first visit. Due to the nature of the RF being used to control the accelerator beam current, it is essential that the control room have accurate knowledge of frequencies levels. As a result, Fermilab precisely and consistently maintains the real time frequency value using state-of-the art frequency counters. NIOSH was informed that the RF frequency ranged from 30 to 200 MHz at various locations within the laboratory (see Figure 2). In some locations, the RF radiation is pulsed and in other cases it is of a continuous nature. Fermilab personnel clearly documented to NIOSH its ability to measure the absolute frequency levels in both situations.

The following instrumentation was used by NIOSH to measure RF radiation due to its ability to properly respond to the frequency and temporal nature of the fields produced at the Fermilab:

1. Narda model 8616 electromagnetic radiation monitor

2. Narda model 8633 isotropic magnetic field probe. This probe measures magnetic field intensities in units of mW/cm^2 over the frequency range from 10 to 300 MHz. This value can be expressed in units of A^2/m^2. The minimal detectable meter deflection level (MDDL) for this probe is determined to be 1.33×10^{-3} A^2/m^2.

3. Narda model 8662B isotropic electric field probe. This probe measures the electric field intensities in units of mW/cm^2 over the frequency range from 0.3 to 1000 MHz. This value can be expressed in units of V^2/m^2. The MDDL for this probe is determined to be 37.7 V^2/m^2. Since the Narda instrumentation indicates units of equivalent free space power density (mW/cm^2) it was necessary to calculate for all data obtained either the electric or magnetic field strength value to compare against the ANSI C-95.1 standard.

4. A body current detector system was also used to measure and confirm the presence of RF fields. The detector system is based on the principle that when RF energy is absorbed by the body, electrical currents are induced within the body [9]. In order to measure these body currents, a special current sensor was built by NIOSH that is designed to respond only to currents induced by external electric fields [10]. At present, body currents induced by magnetic fields can not be measured. The body currents were measured by having workers stand on a 6 mm thick 32 x 32 cm polyethylene sheet clad on both sides with copper. The current from the upper copper plate, where the worker stands, passes to the lower copper plate, which is in contact with the floor surface, through a 5 ohm, 1/4 watt non-inductive carbon resistor, located near the center of the bi-layer sensor. The impedance (Z) of the resistor connected to the sensor was accurately measured over a

wide range of frequencies using a calibrated vector impedance meter. The RF voltage (V) across the resistor was measured using Ballantine model 3440A programmable 1.2 GHz RF millivoltmeter. The voltmeter measures true root-mean-square (RMS) voltages from 0.1 to 3000 mV, even if the input voltage is non-sinusoidal. The measured voltages and impedances were used to calculate the body current (I) according to the relationship:

$$I = V/Z$$

All current measurements were made with the worker standing on the sensor plate with shoes off (Figure 3). This was done because previous work with this system had demonstrated this situation yielded maximum induced current levels. Also, a "background" measurement was made without the worker in order to eliminate spurious readings from sources of electromagnetic interference. In this survey, body current results were used to verify low levels of RF, in the frequency region less than 50 MHz, being absorbed by workers. Measurements using this system were limited to the Linac and Booster areas.

5. Static magnetic fields were measured with a Walker Scientific model MG-50P gaussmeter. This meter works on the Hall effect principal and is designed to measure both DC and AC (RMS) magnetic fields over the range from 0.0 to 10,000 Gauss.

All instruments used in this survey had been calibrated within 60 days of use by either their manufacturer or by NIOSH using appropriate calibration techniques and procedures.

Measurements of RF radiation were made at selected equipment and/or work areas in the Linac, Booster, RF Station, and Main Ring areas. The Linac area was selected due to the largest number of workers potentially exposed and the Main Ring/RF Station selected because it had never been assessed. In addition, measurements were recorded during a simulated general public guided tour and also at a end-users experimental station set up. Finally, area measurements were made at other locations including along the row of offices located by the Linac walkway, within the medical complex, various workstations where employees were located, in the control room, etc. Static magnetic field density measurements were obtained at selected areas within the Linac, bubble chamber, and end-user experimental station.

VI. RESULTS AND DISCUSSION

The linear accelerator (Linac) area has nine, 5 Megawatt amplifiers (see Figure 4 for picture of system) operating at a carrier frequency near 200 MHz. The signal is pulse modulated at a pulse repetition frequency of 15 Hz and a pulse width of 400 microseconds. Measurements were made all around the amplifier, close to the modulator cabinet window and door, and underneath the amplifier. The front windows on the cabinets had been previously identified by Fermilab as a potential location for RF emission. Each cabinet had two windows located about 5 feet off the floor. Each window was surveyed with both the E- and H-field probes as close as possible to the window without contact. In performing these measurements the probes were slowly scanned over the entire window and the highest reading obtained anywhere over the window area was recorded (Figure 5). The highest values for field strength were 3016 V^2/m^2 and 0.002 A^2/m^2 from the 18 sampled windows. No electric or magnetic field strength levels above the MDDL were found when the modulator cabinet doors were scanned. All other sites scanned in and around the linear amplifier also did not yield field strength levels above the MDDL.

Measurements made in and around the power amplifier hose connections did not exceed the MDDL for both the electric and magnetic fields. A value of 0.024 A^2/m^2 was found on the floor below the Number 9 power amplifier. All RF values recorded in the hallways and near the medical area were at or below the MDDL.

The static magnetic fields values ranging from 0 to 700 Gauss were measured in the hallway, around the nine power amplifiers, and in the area adjacent to the Cockroft-Walton accelerator. A piece of plexiglas® had been installed under each of the amplifiers to limit access to the higher fields found underneath the unit (Figure 6). The presence of the plexiglas® helped to define the region where tools would not be drawn into the hole in the floor and strike workers below. Table 1 shows the difference in magnetic fields recorded inside the plexiglas® to those measured outside the plexiglas®. The table also shows other measurements taken around the amplifiers and in the walkway next to the amplifiers at waist height.

There were a total of eighteen 100 kW amplifiers in the booster accelerator area. The carrier signal is both pulse and frequency modulated. Measurements were made on the front window of the booster cabinet, front tuner of the booster magnet, and along the hallways. All windows on the cabinets gave RF levels at or below the MDDL. Static fields in the wallways of the booster area were 1-3 Gauss. All body current values measured at Fermilab were below 1 mA under all conditions of use. Such levels supported the measurements obtained from electric and magnetic field strengths.

Results of electric and magnetic field strength measurements found in the RF test area were all below the MDDL. Measurements taken in the control room and along areas visited on the Fermilab guided tour were all less than the MDDL of the equipment.

The only significant static field measurements found at Fermilab were recorded at the Bubble Chamber and at the end-user experimental area. Bubble chambers are devices that contain liquid hydrogen in a superheated state. When a charged particle enters the chamber to produces ions, bubbles are produced. These bubbles form a pattern that can be recorded on photographs when a brief light flash is produced. Upon study of the photographs scientists can determine information on the momentum and energy of the incoming particles. The plot of magnetic field as a function of distance from the Bubble Chamber is shown in Figure 7. The results shown on the figure reflect both NIOSH measurements and recent data obtained by Fermilab. At positions close to the chamber, levels could be as high as 20,000 Gauss. The only group of workers that would be at risk are probably film operators that change the film cassettes. Such operations take about 5 minutes to complete and occur three times a day (8-hour work shift). There are approximately 10-12 workers that exchange film cassettes. These workers have been extensively monitored medically for the last 10 years and, in discussions with Fermilab medical office and selected workers there has been no evidence of medical symptons or complaints in those workers. Presently, there are plans to remove this bubble chamber from operation before the end of 1988.

VII. CONCLUSIONS

NIOSH investigators believe that based upon the results obtained on the days of measurement and existing evaluation criteria, exposure to radiofrequency radiation at Fermilab is not an occupational hazard. Static magnetic field levels were found to be quite low, except for the levels measured near the Bubble Chamber.

VIII. RECOMMENDATIONS

Based on observations and measurements made over the three day visit, the following recommendations are offered :

1. Fermilab should purchase appropriate field monitoring instruments for use at the various areas within the facility (especially service and maintenance workers). If in the opinion of the Fermilab staff appropriate measurement instrumentation does not exist for their needs perhaps a contractual effort be undertaken to resolve the needs. Since Fermilab serves as the "lead lab" for Department of Energy facilities, invitation could be issued to leading RF instrumentation companies for them to develop appropriate instrumentation for use at Fermilab. Not only would such a effort be important for Fermilab, but the effort would have spin off applications for other laboratories and the occupational health community at large.

2. The Health and Safety Division should continue to monitor for levels of static magnetic fields. It is important that such levels be monitored and published so that occupational standards can incorporate environmental exposure data. In this same regard it is also important that adverse health effects be investigated for workers exposed on a short-term basis or chronically.

3. It is recommended that Fermilab obtain a copy of the previous DOE study on magnetic field exposure performed at the laboratory for their information (particularly, since the largest source of static magnetic fields, the bubble chamber, will soon be dismantled). All data from these magnetic sources should be collected and maintained for future use, especially in areas where magnets are made.

4. Within the booster area we found several instances where plastic reflectors are mounted over various amplifiers and other electronic equipment to serve as splatter guards for possible water leaks that occur where windows are located in the ceiling. This situation is best solved by eliminating the source of potential water rather than allowing the water to enter a area where its presence could create an electrical shock hazard.

5. Many electronic cabinets in the areas surveyed contained items such as paper, cloth, box cartons, cigarette butts, etc. Such items could represent, under certain conditions, a fire hazard. It is suggested that some enforcement program be instituted to minimize this problem.

IX. <u>REFERENCES</u>

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X. AUTHORSHIP AND ACKNOWLEDGMENTS

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XI. DISTRIBUTION AND AVAILABILITY OF REPORT

Copies of this report are available upon request from NIOSH , Division of Standards Development and Technology Transfer, Publications Dissemination Section, 4676 Columbia Parkway, Cincinnati, Ohio 45226. After 90 days, the report will be available through the National Technical Information Service (NTIS), 5285 Port Royal, Springfield, Virginia 22161. Information regarding its availability through NTIS can be obtained from NIOSH Publications Office at the Cincinnati address. Copies of this report have been sent to:

1. Fermilab, Batavia, Illinois
2. DOE, Chicago Regional Office
3. NIOSH, Cincinnati Office.
4. OSHA, Region V.

For the purpose of informing affected employees, copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 calendar days.

Table 1

Levels of Static Magnetic Field Density in Gauss
Measured in LINAC Area Near Base of Amplifiers
Both Inside and Outside Plexiglas® Barrier

Fermilab
Batavia, Illinois
HETA 87-329

January 20, 1988

Station Number	S/N	Inside Barrier	Outside Barrier	1 M away at waist
1	5	12	70	0
2	7	18	230	0
3	9	30	510	0
4	6	77	620	0
5	2	83	560	3
6	4	51	670	7
7	8	43	560	7
8	3	88	700	27
9	1	45	622	73

Figure 1. Aerial View of Fermilab

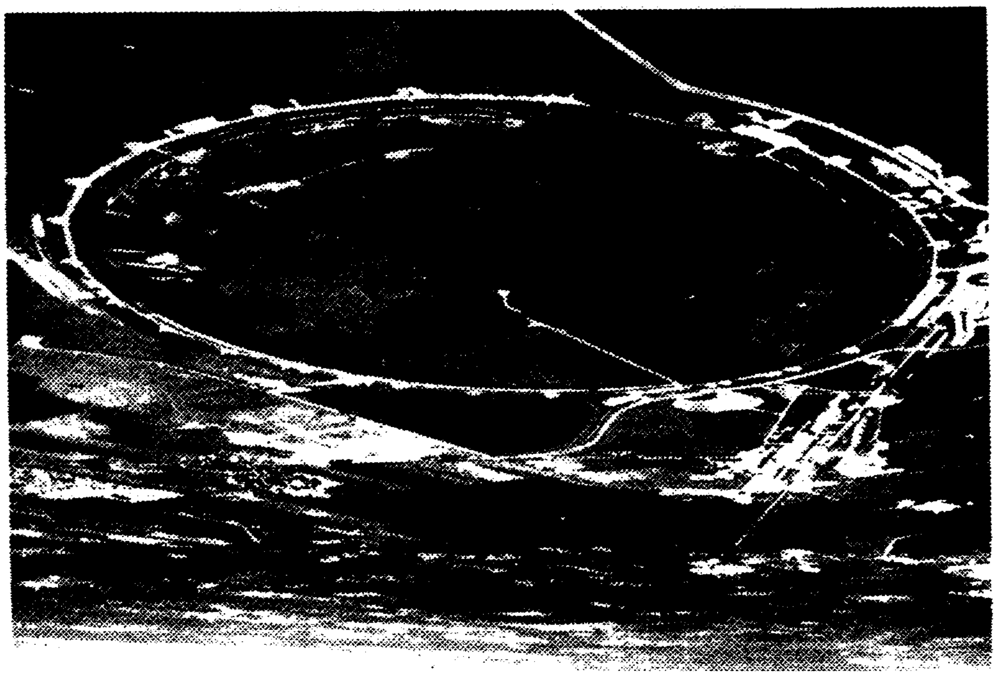

Figure 2. Change in Overall RF Freguency as Function of Location in Fermilab

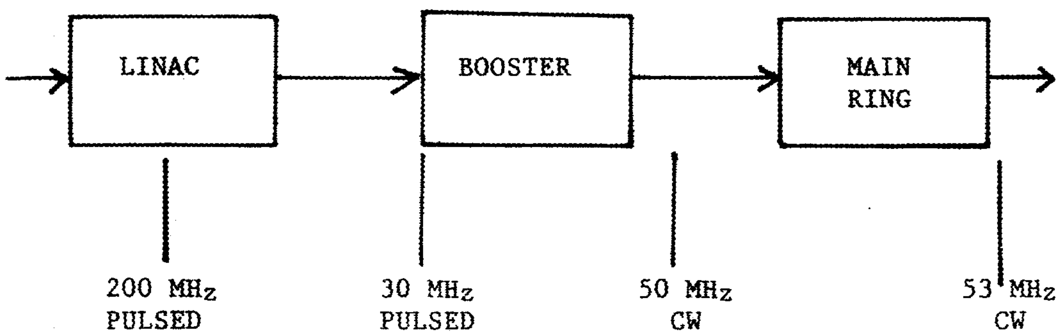

Figure 3. Measurement of Body Currents Induced by Magnetic fields at Preamplifier Cabinet

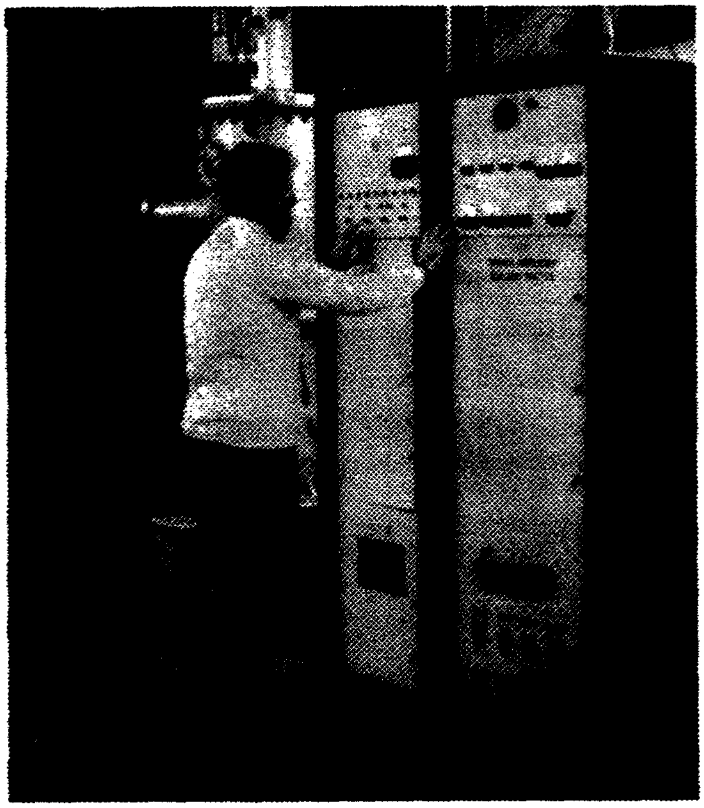

Figure 4. Preamplifier cabinet, power amplifier, and modulator cabinet (R to L)

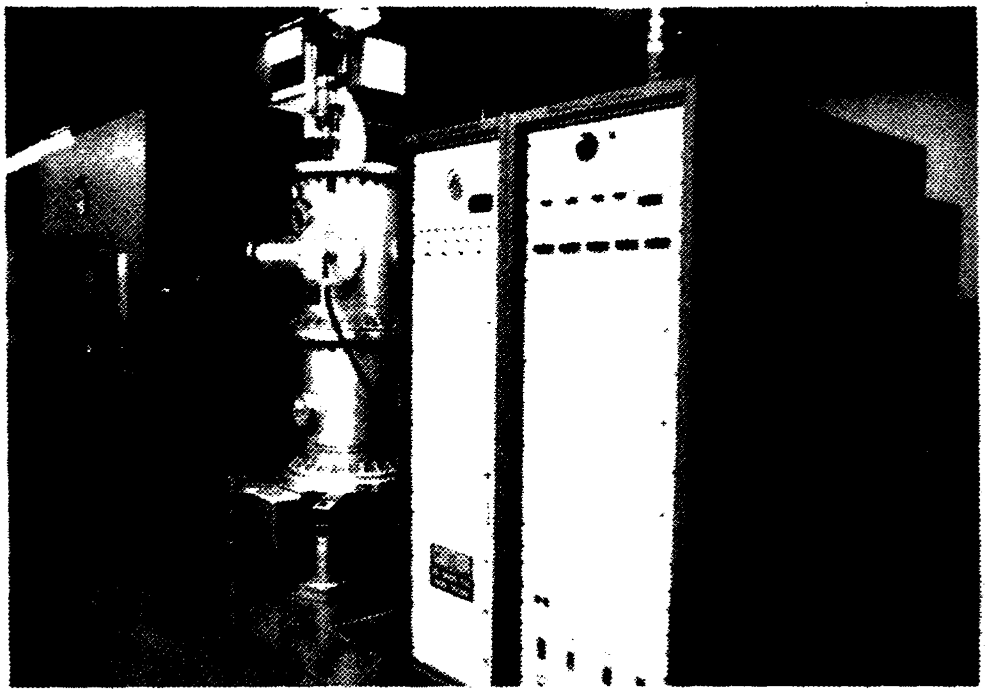

Figure 5. Measurement of E or H field strength at window of modulator cabinet

Figure 6. Measurement of Static Magnetic field at base of power amplifier

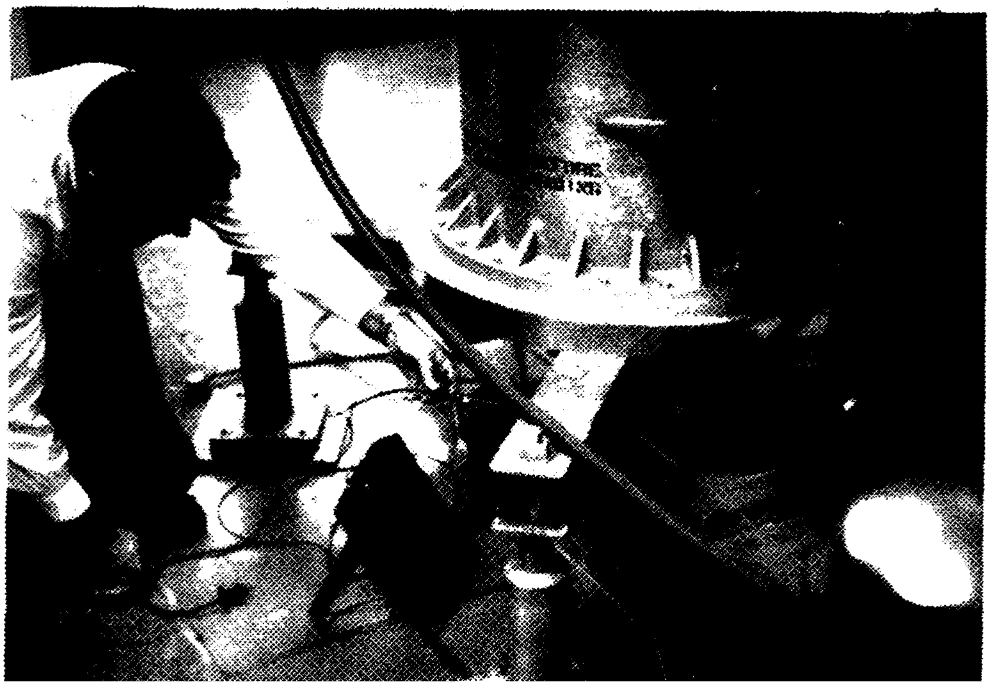

FIGURE 7. **Measured static magnetic field density in gauss as function of distance from center of various magnets at Fermilab.**