FESHM 4270: STATIC MAGNETIC FIELDS

Revision History

Author	Description of Change	Revision Date
Matt Quinn & David Baird	Fermilab Environment Safety Health Manual (FESHM) 4270, *Static Magnetic Fields* replaces FESHM 5062.2, *Static Magnetic Fields*. The chapter was revised during its five-year review. In March, 2015, Fermilab decided to adopt the current (2015) version of the American Council of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs). These values are in line with increased values adopted by ACGIH in 2010, and reflect updated knowledge of the biological effects of static magnetic fields. Changes to the chapter include: • The text was rewritten to reflect improved knowledge of the biological effects from magnetic fields and to align the format with that of other industrial hygiene chapters. • The exposure limits are unchanged and are set equal to the 2015 ACGIH TLVs. The whole body values for general workers and medical device wearers are unchanged. The TLV for limbs is increased in Section 4.0, Procedures. • The TLVs now omit the 8-hour Time Weighted Average, and include a separate limit (also in Section 4.0) for workers with special training and controlled workplace environments. • Chapter updated to new FESHM Format along with references to Environment, Safety and Health (ESH) Section changed to Environment, Safety, Health, and Quality (ESH&Q) Section.	July 2015

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1.0 INTRODUCTION

Particle accelerators and associated detectors often rely on intense static magnetic fields in order to operate. Because of this, one might assume that people at Fermilab are regularly exposed to magnetic fields. For the most part, this is not the case. The fields associated with most of Fermilab's magnets (i.e., accelerator magnets) are constrained to their interiors and present little hazard. On the other hand, there are a few analyzing magnets that can present exposures that are comparable to those encountered in medical magnetic resonance imaging (MRI) scanners. Other sources of static magnetic fields are more typical of a general work environment such as permanent magnets, electromagnets used for lifting, and steel products with residual magnetization.

The primary hazard associated with static magnetic fields is difficulty handling ferromagnetic items. There is a rotational force causing objects to align with field lines. In addition, there can be a translational force that pulls objects toward the source of a magnetic field. Magnetic fields can also interact with implanted metallic or electronic devices, and there can be direct interactions with biological systems. This chapter describes Fermilab's program and procedures for addressing the exposure to static magnetic fields.

2.0 DEFINITIONS

Ferromagnetic – Materials that exhibit a strong attraction to magnetic fields and are able to retain magnetic properties after the external field has been removed. Iron, nickel, and cobalt are examples of ferromagnetic materials.

Magnetohydrodynamic – Refers to the interaction of magnetic fields and electrically conducting fluids such as blood.

Phosphenes - Brief spots of light brought on by eye movement that last for less than a few seconds.

Tesla – SI unit of magnetic flux density (B). 1 tesla = 10,000 gauss. The symbols for tesla and gauss are T and G, respectively.

Vestibular - Having to do with the body's system for maintaining equilibrium.

3.0 RESPONSIBLILITIES

3.1 Division Safety Officer:

Work with potentially-exposed personnel, managers, the Medical Department, and the Environment, Safety, Health and Quality Section (ESH&Q) in assessing exposures, designing controls, training, and providing signs and labels.

3.2 Supervisor:

Assist in identifying potential exposures and in implementing any necessary controls. Supervisors have a key role in assuring that their employees adhere to requisite behaviors.

3.3 ESH&Q:

Assist affected divisions/sections in providing technical advice in this chapter, assessing exposures, designing controls, training, and providing signs and labels.

3.4 Medical Department:

Screen potentially-exposed personnel for the presence of medical devices and conditions for which static magnetic field exposure may pose an increased risk. Work with potentially-exposed personnel, their management, and ESH&Q staff to limit static magnetic field exposures to levels that will reduce the risk of harm to acceptable levels.

3.5 Employee:

Assist in identifying potential exposures and in implementing any necessary controls. Adhere to requisite safety behaviors.

4.0 PROCEDURES

1. Program – There are three components to Fermilab's static magnetic field program: controlling the mechanical hazards of ferromagnetic items, restricting access of personnel with medical electronic and/or metallic implants, and controlling the exposures to all other personnel. Ferromagnetic items can be largely handled in an empirical fashion: if the presence of the magnetic field presents a hazard, make appropriate adjustments. In order to restrict access of personnel with medical implants, they must first be identified. Though such personnel may volunteer this information, the involvement of the Medical Department is still appropriate. Finally, controlling exposures is a matter of monitoring and posting.

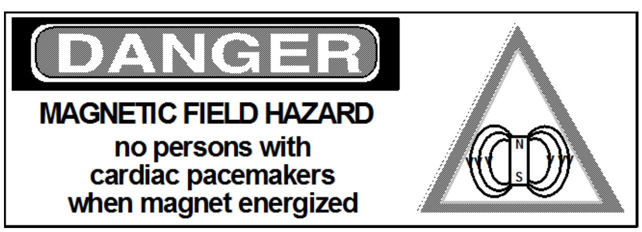
2. Exposure limits - The values given below refer to static magnetic fields to which it is believed that nearly all workers may be repeatedly exposed without experiencing adverse health effects (2015 American Council of Governmental Industrial Hygienists Threshold Limit Value for Static Magnetic Fields).

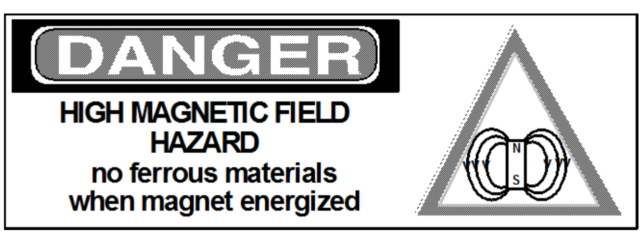
Target area	Ceiling
Whole body (general workplace)	2 T / 20,000 G
Whole body (special worker training and controlled workplace environment)	8 T / 80,000 G
Limbs	20 T / 200,000 G
Medical electronic device wearers	0.5 mT / 5 G

3. Monitoring - Divisions/Sections managing activities involving static magnetic field sources are responsible for arranging industrial hygiene monitoring whenever exposures are reasonably expected to meet or exceed limits. If results do not exceed exposure limits, further monitoring is not required unless the activity is modified in a way that is expected to increase exposures.

   Static magnetic field exposure limits were established assuming a homogeneous field. For inhomogeneous fields, the magnetic flux density should be averaged over 100 centimeter (cm) squared. This approach should be especially useful when dealing with dimensionally small sources.

4. Posting – There are two types of static magnetic field warning signs: one is for pacemaker hazards (> 0.5 mT / 5 G), while the other is for higher intensity general magnetic field hazards (>2T / 20,000 G or more). Appropriate signs should be posted in a way that best serves to warn potentially exposed personnel. Suggested sign layouts are shown below.





Other layouts and/or wording may be used as best suits the nature of the static magnetic field source(s) and potentially exposed individuals.

5. Medical surveillance – Potential exposures to high magnetic fields should be identified by supervisors via each employee's Work Activities Analysis Form (WAAF - http://www-esh.fnal.gov/pls/default/WAAF.html).

   Persons with metallic implants (excluding dental fillings), metallic prosthesis, metallic fragments (especially in eyes), medical electronic devices, or active sickle cell anemia should be prohibited from the area unless permitted by the Occupational Medicine Director.

   Medical electronic devices include cardiac pacemakers, cardiac defibrillators, hormone infusion pumps (e.g., for insulin), neuromuscular stimulation devices (e.g., for the sphincter muscle of the bladder), and electronically operated prosthetic devices (e.g., for the limbs and inner ear).

5.0 REFERENCES

American Conference of Governmental Industrial Hygienists (ACGIH): Documentation of the Threshold Limit Values for Physical Agents, static magnetic fields (2015).

International Commission on Non-Ionizing Radiation Protection (ICNIRP): ICNIRP Guidelines, GUIDELINES ON LIMITS OF EXPOSURE TO STATIC MAGNETIC FIELDS (2009). HEALTH PHYSICS 96(4):504-514;2009

http://www.icnirp.org/cms/upload/publications/ICNIRPstatgdl.pdf

6.0 TECHNICAL APPENDICES

6.1 Review of static magnetic field hazards

Handling ferromagnetic items – Care must be exercised regarding the rotational and translational forces that act upon ferromagnetic items located in a static magnetic field. Rotational forces may be noticeable above 6 millitesla (mT) (60 gauss [G]) and cause difficulty around 60 mT (600 G). Translational forces may be noticeable above 10^{-4} T^2/meter (m) (10^2 G^2/centimeter[cm]) and equal to gravity above 10^{-3} T^2/m (10^3 G^2/cm). A practical approach to evaluating this hazard is to introduce a non-hazardous ferromagnetic item into the magnetic field and map the boundary where handling becomes difficult.

Non-magnetic tools are available that are made from aluminum bronze, titanium, or copper beryllium. However, the presence of beryllium in copper beryllium tends to make this a poor choice of material (see Chapter 4190 - SPECIAL TOXIC HAZARDS Beryllium and Beryllium Alloys Chronic Beryllium Disease Prevention Program).

Medical implants – The effects of static magnetic fields on medical implants has been extensively studied in the context of magnetic resonance imaging. Of the various electronic devices evaluated, cardiac pacemakers are considered the most sensitive. This is because they have a magnetic reed switch that changes pacing from *demand mode* to *fixed-rate pacing*. Most pacemakers will switch at 2 mT (20 G), but fewer than 2% are affected at 0.5 mT (5 G). In addition to electronic devices, many implanted medical devices contain ferromagnetic materials that impose forces from static magnetic fields. This can lead to movement and/or potential dislodging of implanted metallic devices. There can be significant forces on large items such as hip prostheses, but there can also be effects on aneurysm clips, metal surgical clips and stents, heart valve prostheses and annuloplasty rings, metallic contraception implants, metallic cases of implanted electronic devices, and metallic dental implants. However, there is no evidence that static magnetic fields of 0.5 mT (5 G) exert sufficient forces to present a hazard.

Direct biological effects – Human exposures up to at least 8 T (80,000 G) do not appear to be associated with any long-term health effects. However, exposures over 2 T (20,000 G) can lead to unpleasant sensory effects as well as minor transient alterations in performance. These effects include vertigo, nausea, metallic taste, and phosphenes when moving the eyes or head. The severity of these symptoms increases with the rate of motion.

Vertigo apparently results from both magnetic susceptibility differences between vestibular organs and surrounding fluid, as well as induced currents acting on the vestibular hair cells. Nausea is probably caused by vertigo. The mechanism for metallic taste is likely electrolysis of saliva (detected as acid taste). Phosphenes are caused by current induced within the optic nerve resulting in the illusion of light.

A statistically significant 4% increase in systolic blood pressure has been measured at 8 T (80,000 G). This change matched magnetohydrodynamic predictions, but is clinically insignificant. Another cardiac effect is an apparent increase in the T-waves of electrocardiograms in static magnetic fields exceeding 0.1 T (1000 G). This is due to blood flowing in the heart and major vessels and is apparently harmless. The presence of these induced voltages has been demonstrated in rodents, dogs, baboons and monkeys.

There have been limited epidemiological studies on workers exposed to static magnetic fields of up to several tens of mT (hundreds of G) either in aluminum smelters, chloralkali plants, or as welders. Results suggest an increase various cancers, but statistical significance and control populations have been lacking.

6.2 Magnetic forces on ferromagnetic objects

Ferrous objects can experience rotational and translational forces when immersed in a magnetic field. These forces can increase the risk of accidents associated with the use of common work materials (such as tools, carts, gas cylinders, and safety shoes) as well as that of medical emergencies (such as the removal of aneurysm clips).

Rotational Force

The torque experienced by a ferrous object depends on the magnetic field strength:

$$L_{mag} = -mH\sin\theta$$

Where
L_{mag} = torque experienced by the ferrous object (Newton[N]-m)
m = magnetic moment of the ferrous object (Weber-m)
H = magnetic field density (amperes/m)
θ = angle between the magnet moment and the field (^{o})

The following table summarizes observations made by T. Miller and J. Kenny in 1987 at the Fifteen Foot Bubble Chamber. These effects were observed using a wrench, nail, pen, clip board, safety shoes, and gaussmeter.

These results neatly match whole body exposure limits: significant interference at the 60 mT (600 G) personnel exposure limit.

Approximate field strength		Rotational force observation summary
mT	**G**	
< 6	< 60	No perceptible rotational force
≈ 60	≈ 600	Rotational force clearly interferes with use of ferrous objects
> 200	> 2000	Rotational force makes normal handling of ferrous objects almost impossible

Translational Force

The translational magnetic force can be calculated from the gradient of the change in the magnetic field energy density resulting from the presence of the ferrous object in the magnetic field.

$$\vec{F}_{mag} = \nabla[(U - U_0)V]$$

Where F_{mag} = magnetic force on the ferrous object (N)
∇ =gradient operator
U = energy density with ferrous object (Joules [J]/m^3)
U_o = energy density without ferrous object (J/m^3)
V = volume of ferrous object (m^3)

The magnetic field energy density is given by:

$$U = \frac{1}{2}\vec{B}\cdot\vec{H}.$$

Where B = magnetic flux density (T)
H = magnetic field density (A/m)

The magnetic flux density in the absence of the ferrous object is

$$\vec{B}_0 = \mu_0\vec{H}.$$

Where μ_o = permeability of free space = 4π x 10^{-7} Henry [H]/m

If it is assumed that the ferrous object is spherical (since other geometries are incredibly complicated), the internal magnetic flux density is [Pl78]:

$$\vec{B} \approx 3\mu_o \vec{H}.$$

Therefore, the magnetic force is approximately

$$\vec{F}_{mag} = \nabla\left\{\left[\frac{1}{2}(3\mu_0\vec{H}\cdot\vec{H}) - \frac{1}{2}(\mu_0\vec{H}\cdot\vec{H})\right]V\right\}$$

$$\vec{F}_{mag} = \nabla(\mu_0 H^2 V) = \nabla\left(\frac{V}{\mu_0}B_0^2\right)$$

$$F_{mag} = \frac{2V}{\mu_0} B_0 \frac{dB_0}{dr}$$

V = velocity of charged particle (m/second [s])

∇= gradient (T^2/m)

It is now possible to determine the field conditions which result in the translational magnetic force that can be expected to interfere with normal handling. We will assume this occurs when the translational force is equal to one-tenth the force due to gravity. In addition, we will assume that the object is an iron sphere.

$$F_{mag} = 0.1\, F_{grav}$$

$$\frac{2V}{\mu_0} B_0 \frac{dB_0}{dr} = 0.1\, \rho V g$$

$$B_0 \frac{dB_0}{dr} = \frac{0.1\mu_0 r g}{2} = \frac{(0.1)(4\pi x 10^{-7}\frac{H}{m})(7900\frac{kg}{m^3})(9.8\frac{m}{s^2})}{2}$$

$$B_0 \frac{dB_0}{dr} = 4.9x10^{-3} \frac{T^2}{m} \; (= 4.9x10^{3} \frac{G^2}{cm})$$

Limited measurements made in 1987 *suggest* that translational forces may be "noticeable" above 10^{-4} T^2/m (10^2 G^2/cm) and equal to the gravitational force above 10^{-3} T^2/m (10^3 G^2/cm). However, a subset of the observations indicate that much higher values - up to 100X - are needed to produce problematical translational forces.