TRIUMF

Safety Note

SAFETY NOTE 6.10.0:

Hazards Associated with Static Magnetic Fields

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History of Changes

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Scope

This Safety Note describes the hazards associated with static magnetic fields such as those produced by magnets used at the TRIUMF facility. Limits for short and long-term exposure are listed. Precautions are given for individual that have implanted medical devices.

Who should read this document

This note is required reading for all workers at TRIUMF that work near energized magnets. Those who escort visitors or tours around the TRIUMF facility should also read this Safety Note.

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Section 1: Introduction

The magnetic fields associated with most magnets used at TRIUMF are constrained to their interiors and hence do not present an exposure hazard. The notable exceptions are fields from the cyclotron magnets and the analyzing magnets that are extensively employed in some of the experimental areas of the 500 MeV facility. The static magnetic fields from these devices may be as high as several tesla and, though the intensity decreases rapidly with distance, may require many meters to drop to negligible levels. The hazards of exposure to static magnetic fields include forces on ferrous objects and interference with various medical devices (especially cardiac pacemakers and ferrous implants/prostheses).

Other effects have not been shown to be harmful. This note describes procedures to control the hazards associated with exposure to static magnetic fields.

Section 2: Special Responsibilities

Persons controlling devices that produce magnetic fields in excess of those identified in Table 1.5-1 below are responsible for addressing the hazards associated with these devices as part of the safety analysis for their experiment or facility. They are responsible for the mounting and upkeep of all required warning signs and barriers.

In addition to screening personnel for cardiac pacemakers, metallic implants, metallic prostheses, medical electronic devices, Human Resources is responsible for informing new employees about the hazards of exposure to static magnetic fields and notifying their supervisor regarding the presence of such personnel.

Section 3: Hazards Associated with Static Magnetic Fields

1.1 Quantities and Units

A magnetic field can be represented as a vector and may be specified in one of two ways: as a magnetic flux density *B*, or as magnetic field strength *H*. *B* and *H* are expressed in teslas (T) and amperes per meter (A m^{-1}), respectively. In a vacuum and in air, B and H are related by the expression

$$B = \mu_0 H$$

The constant of proportionality μ_0 is termed the permeability of free space (or any non-magnetic material) and has the numerical value $4\pi\times10^{-7}$ expressed in henrys per meter (H m^{-1}). The magnetic flux density is accepted as the most relevant quantity for relating magnetic field effects. A general summary of magnetic field quantities is provided in Table 1.1-1.

Table 1.1-1: Static magnetic field quantities and corresponding SI units.

Quantity	Symbol	Unit
Current	I	ampere (A)
Current density	J	ampere per square meter (A m^{-2})
Magnetic field strength	H	ampere per meter (A m^{-1})
Magnetic flux	Φ	weber (Wb) = volt s=tesla m^2
Magnetic flux density	B	tesla (T)=Wb m^{-2}
Permeability	μ	henry per meter (H m^{-1})
Permeability of free space	μ_0	$\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}

Although the SI system has now been universally accepted, magnetic field quantities are still often quoted in older units. For convenience, the conversion factors relating the SI units to these older units are given in Table 1.1-2.

Table 1.1-2: Conversion factors for magnetic quantities.

	Tesla (=weber m^{-2})	Gauss	Ampere/m	Oersted
Tesla (=Weber m^{-2})	1	10^4	7.96×10^5	10^4
Gauss	10^{-4}	1	79.6	1
Ampere/m	1.256×10^{-6}	1.256×10^{-2}	1	1.256×10^{-2}
Oersted	10^{-4}	1	79.6	1

1.2 Natural Magnetic Fields

The natural magnetic field consists of one component due to the earth acting as a permanent magnet and several other small components, which differ in characteristics and are related to such influences as solar activity and atmospheric events.

The earth's magnetic field originates from electric current flow in the upper layer of the earth's core. There are significant local differences in the strength of this field. At the surface of the earth, the vertical component is maximal at the magnetic poles, amounting to about 6.7 x 10^{-5} T (0.067 mT) and is zero at the magnetic equator. The horizontal component is maximal at the magnetic equator, about 3.3 x 10^{-5} T (0.033 mT), and is zero at the magnetic pole.

1.3 Risks of Chronic Exposure

Table 1.1-2 lists a number of studies of workers exposed to static magnetic fields as published in a report by the World Health Organization. The studies that have reported some effects are those that had less than adequate controls and no real measure of the exposure to magnetic fields, such as those in the aluminium production plants. There is only one study on workers at high-energy accelerator laboratories (high-lighted row). This study did not find any increase in the prevalence of 19 common diseases, including cancers.

Exposure to the low stray magnetic fields at TRIUMF is therefore not considered to be a health hazard.

Table 1.3-1: Studies of workers exposed to static magnetic fields (World Health Organization, Geneva, 1987)

Exposure Characteristics	Reported effects (exposed population)	Reference
Workers in magnet production; average exposure: 2-5 mT (hands), 0.3-0.5 mT (chest and head)	Subjective minor and physiological effects (645 exposed, 138 controls, no statistical analysis)	Vyalov (1974)
Workers in aluminium plants (no fields reported)	Increased risk of leukaemia (death records of 438 000 males, but few cases)	Milham (1979, 1982, 1985b)
Industries using electrolytic cells (average, 7.6 mT; maximum, 14.6 mT)	Minor haematological alterations, but no major health effects (320 exposed, 186 controls)	Marsh (1982)
Workers in aluminium plants (no fields reported)	Small excess of leukaemia mortality; non-significant risk of other cancers	Rockette & Arena (1983)
High energy accelerator laboratory (fields up to 2 T)	**No increased prevalence of 19 common diseases including cancers (792 exposed, 792 controls)**	**Budinger et al. (1984b)**
Electrolytic production of chlorine (fields4 – 29 mT)	No increased incidence of cancer over 25-year period	Barregard et al. (1985)

1.4 Immediate Risks

Ferrous objects can experience rotational and translational forces when immersed in a magnetic field. Depending on the weight and shape of the object subject to an intense magnetic field, it can become a missile with high momentum. 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).

Table 1.4-1 summarizes observations made by T. Miller and J. Kenny in 1987 at the Fifteen Foot Bubble Chamber at Fermilab. These effects were observed using a wrench, nail, pen, clipboard, safety shoes, and gauss-meter.

Table 1.4-1: Observation of strength of rotational force in static magnetic fields

Approximate Field Strength		Rotational Force
(mT)	Gauss	
<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

Both static and time-varying magnetic fields can interfere with the proper functioning of modern demand pacemakers. Cardiac pacemakers use magnetically activated reed switches to alter their operating mode. Normally, pacemakers sense and amplify the heart's natural pacing signal. In the alternate safety backup mode pulses are sent out at a fixed rate. The magnetic switch is provided to allow testing of the backup mode by holding a permanent magnet to the person's chest. In seriously ill individuals, the fixed frequency signal could destructively compete with the heart's natural pacing signal. Some pacemakers may revert from a synchronous to an asynchronous mode of operation in time-varying fields with time rates of change above approximately 40 mT/s. Certain pacemaker models also exhibit abnormal operation due to closure of the reed relay switch in static magnetic fields that exceed 1.7 - 4.7 mT.

The sensitivity of implanted surgical devices to magnetic fields is dependent on their alloy composition. A large number of metallic devices such as intrauterine devices, surgical clips, prostheses, infusion needles, and catheters may have a significant torque exerted on them by intense magnetic field gradients. This may result in their displacement and produce serious consequences.

All persons entering magnetic field environments should be screened carefully and, if necessary, prohibited from access.

Section 4: Exposure Limits

1.5 ICNIRP

The International Commission on Non-ionizing Radiation (ICNIRP) has published a set of limits for exposure to static magnetic fields. These are reproduced in Table 1.5-1.

Table 1.5-1: Limits of exposure to static magnetic fields

Exposure characteristics		Magnetic flux density
Occupational	Whole working day (time-weighted average)	200 mT
	Ceiling value	2 T
	Limbs	5 T
General public	Continuous exposure	40 mT

Whole-body, continuous occupational exposure during the working day should be limited to a time-weighted average magnetic flux density not greater than 200 mT. Occupational whole-body exposure should never exceed a magnetic flux density ceiling value of 2 T. When restricted to the limbs, exposures up to 5 T can be permitted.

Continuous exposure of members of the general public should not exceed a magnetic flux density of 40 mT.

People with cardiac pacemakers, ferromagnetic implants and implanted electronic devices *may not be protected* by the limits given in Table 1.5-1.

The majority of cardiac pacemakers are unlikely to be affected in fields less than 0.5 mT (5 gauss); therefore, cardiac pacemaker and implantable defibrillator bearers should avoid locations where the magnetic flux density is greater than 0.5 mT. There are also other vital electronic aids in increasing use [i.e. electronic inner ear protheses, insulin pumps, electronically guided active protheses (e.g. hand, arm, and leg) and muscle stimulation devices (e.g., sphincter muscle and bladder)] that may be susceptible to static magnetic flux densities above a few mT, particularly if the person is moving within the field.

People with ferromagnetic implants should ask their physicians for advice and, in particular, people with aneurysm clips that are not definitely known to be nonmagnetic should not be exposed to magnetic fields above a few mT because of the danger of twisting or dislodgement.

Section 5: Precautions

The following procedures are therefore recommended:

- Workers must never be exposed to fields exceeding 2 T, regardless of the duration of the exposure.
- The exposure of limbs exposed separately from the body must never exceed 5 T;
- The chronic time-averaged field to which workers are exposed must not exceed 200 mT;

In addition, the following restrictions are made:

- Always use cardiac pacemaker warning signs indicating the presence of a magnetic field, whenever the field strength is 0.5 mT or greater.
- Use additional administrative controls or barricades (ropes or fences), whenever practical.
- Do not allow workers with cardiac pacemakers or other medical electronic implants into areas where the magnetic-field intensity exceeds 0.5 mT. Magnetic fields greater than this level can trigger a change in the operating mode of some pacemakers.
- Persons with small metallic implants (such as aneurysm clips) must also be stopped from entering an area where the field intensity is greater than 0.5 mT. Stronger magnetic fields may rotate or even remove aneurysm clips from the arteries to which they are attached.
- Workers with large metallic implants, such as hip prostheses, should be advised to avoid working anywhere inside the perimeter of 10 mT field intensity.