C11 Safety Guidelines for MRI and NMR Equipment

1. Introduction

In the laboratory environment, the most commonly used equipment capable of generating strong magnetic fields are Magnetic Resonance Imaging (MRI) and Nuclear Magnetic Resonance (NMR) systems. The primary hazard associated with magnet field is its attraction of magnetic objects. Secondary hazards associated are cryogenic and electrical hazards. The purpose of this document is to provide laboratory personnel at the Science Park with basic information on safety requirements for installation and operation of these equipment.

2. Definition

2.1 Static Magnetic Field

A magnetic field is a force field created by a magnet or charges that move in a steady flow as in direct current (DC). Static magnetic fields exert an attracting force on metallic objects containing for example, iron, nickel or cobalt. The quantity of ferrite (a form of iron) or martensitic steel (specific type of stainless steel alloy) in an object will affect its magnetic ability: the greater the quantity of these components, the greater the ferromagnetism. Static magnetic fields can erase data stored on magnetic media or on the strips of credit cards and badges.

The unit of magnetic field is usually expressed either as Gauss (G) or Tesla (T) which is the CGS-derived and SI unit of magnetic field strength per unit area respectively. One T equal 10000 G (1T= 10000G or 1mT = 10G).

2.2 Time-Varying Magnetic Fields

Time-varying magnetic fields are magnetic fields that reverse their direction at a regular frequency. They can induce an electric current in a conductor present in this field as well as in a human body. Time-varying magnetic fields are produced by devices using AC such as cellular telephone antennas, microwaves, etc. A general rule of thumb is that 1 T/sec can induce about 1 microampere per square centimeter ($\mu A/cm^2$) in the body. At 10-100 $\mu A/cm^2$ changes in the threshold for nerve and muscle action occur, with a potential health hazard. However, the magnetic field necessary to generate 10 $\mu A/cm^2$ is very large.

2.3 Superconducting Magnet

A superconducting magnet is an electromagnet made from coils of superconducting wire. It must be cooled to cryogenic temperatures during operation. In its

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superconducting state, the wire can conduct much larger electric currents than ordinary wire, creating intense magnetic fields. Superconducting magnets are used in MRI scanners in hospitals/ research laboratories and in scientific equipment such as NMR spectrometers.

MRI or NMR equipment can generate maximum magnetic field strength ranging from 5 to 20T. The earth's magnetic field is around $1x10^{-4}$ T. Equipment generating static or time-varying magnetic fields greater than 0.5 mT (5G) entail appropriate safety control measures.

3. Hazards Associated with MRI and NMR Equipment

3.1 Magnetic Field Hazard

Ferromagnetic and metallic objects (Steel or iron) are strongly attracted to the magnet, and can become potentially lethal projectiles. Personnel can be severely injured and/or equipment can be damaged if hit by objects that are attracted to the magnet at high speed. Therefore, no ferromagnetic and metallic objects are allowed inside a magnet room or within the pre-determined radius of the magnetic field (> 5G). Credit cards, cell phones, camera and magnetic storage media can be damaged or destroyed by the magnetic field and therefore should be stored outside the predetermined magnetic field lines.

3.2 Cryogen Hazard

The superconducting magnet is kept in a cryostat containing both liquid helium and liquid nitrogen for maintaining the extremely low temperature. Both liquids are extremely cold (liquid helium -452°F, liquid nitrogen -320°F), colorless, and odorless. Magnet quenching takes place when a magnet suddenly loses its superconductivity. Due to failure of the superconducting coil or the coil in the cryogenic system becomes resistive and generates heat which leads to explosive expansion of helium gas from the cryostat. The rapid escape of helium displaces the room air and this may lead to asphyxiation if personnel are working in the laboratory with limited space. Depletion of oxygen levels below 18% in the environment starts showing oxygen deficiency effects. When oxygen levels falls below 6% can result in sudden death.

Moreover, contact with liquid or cold vapor can cause severe frostbite. Personnel should wear appropriate personal protective equipment (PPE) when handling cryogens.

3.3 Electrical Hazard

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Superconducting magnets require a large amount of electrical power for operation. This power is proportional to the voltage utilized by the equipment. Proper electrical safety measures must be in place for the installation and use of the equipment.

3.4 Fire Hazard

The cryogenic gases are not flammable; however, the extreme cold condition that exists during and immediately after a quench may cause air to condense and create liquefied oxygen on surfaces. Violent reactions such as rapid combustion or explosion may occur if accumulated oxygen were to come in contact with combustible materials.

3.5 Other Hazard

NMR tubes have thin walls and get broken easily. Majority of accidents take place during the process of capping and insertion of tubes into the magnet. Broken samples can result in injuries or lead to dangerous spills of toxic chemicals.

4. Safety Requirements

To ensure the safety of laboratory personnel, the management of each concerned laboratory shall observe the following safety requirements:

4.1 Facility and Building Services Requirements

a) Magnet Room – MRI or NMR equipment must be located in restricted areas accessible to authorized personnel only. Persons with metallic implants and prostheses such as aneurysm clips, implanted pins, shrapnel, insulin pumps, prosthetic limbs, cochlear implants, pacemakers, and cardiac or neural defibrillators must not be allowed to the room. They should be reminded of the potential hazard.

b) Forbidden Objects – Tools and magnetizable objects must be kept out of places where elevated static magnetic fields are present (>5G). Examples of such objects or tools include work station, fire extinguishers, compressed gas cylinders, screw drivers, tweezers, chairs, flashlights, keys, jewelry, hearing aids, magnetic stirring bars, batteries, watches, scissors and badges, etc.

c) Area Designation – A 5G line must be used to designate the area where the magnetic field strength is larger than 5G. The 5G line is a demarcation between uncontrolled and controlled areas. This line can be denoted with a barrier, such as non-metallic stanchions or plastic chains or a visible warning, such as tape on the floor around the magnet. Whatever method is used, egress from the area in the event of emergency shall not be blocked or prevented. Individuals should be able to enter or exit the room without passing strong magnetic field.

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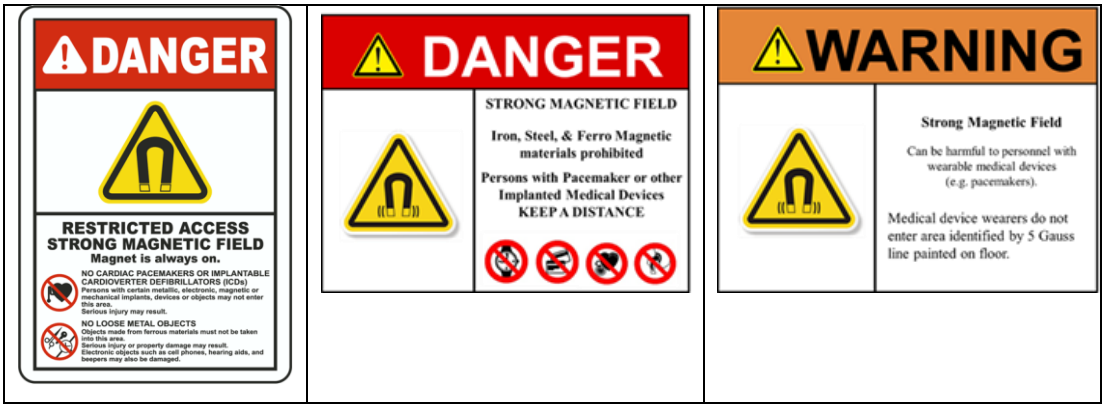
To highlight the designated area within a workplace, it is advised to create a floor plan highlighting the location of the MRI or NMR equipment and the 5G lines covering areas. This floor plan should be displayed at the entrance of that area.

d) Signage – Hazard warning signs are required to be posted at all access points to the magnet room and other areas probably affected by magnetic fields. Examples of such signage are shown below.



e) Magnetic Field Shielding – The static magnetic fields in the facility must be identified by measurement or calculations to determine the installation of magnetic field shielding in order to reduce the magnetic field to less than 0.1 mT (1G) in adjoining rooms and public corridors.

f) Exhaust – Laboratory should be maintained under negative pressure relative to the corridor so that the quenching gases will not spread to the outside corridor so quickly if quenching occurs.
A quench pipe should be installed to allow the quenching gases to escape and discharge to an unoccupied area outside the building. This area is taken as the quench safety exclusion zone and should be clearly marked with warnings and signage. It should be devoid of any serviceable equipment, air intakes, operable windows or unsecured doors that either require servicing or offer a pathway for the gases to re-enter the building.

g) Sensor device – It is advised to install oxygen level sensor in the magnet room with audible alarms when oxygen concentration reaches unsafe levels (<19.5%). To avoid a quench situation, use a cryogen level sensor system to detect the quench and trigger a lowering of the current and stored magnetic energy to prevent burnout of the conductor. Always refill or de-energize the magnet if low cryogen levels are indicated on the sensors.

h) Emergency facilities – Emergency shower, eyewash station and fire extinguisher must be installed outside the magnet room. Spill kit and first-aid kit shall be available at nearby convenient locations.

4.2 Training of Personnel – All personnel working with MRI or NMR equipment should receive training before commencement of work. Training content should include basic information regarding hazard identification, standard operating procedures (SOPs) and emergency response.

5. General Safety Practices

As superconducting magnets or permanent magnets do not require power to sustain their magnetic fields, personnel must be aware that the magnetic fields generated from the equipment cannot be simply "switched off" but always remain on. Laboratory personnel shall adopt the following safety practices during operation with MRI or NMR equipment in the laboratories:

a) Personnel using pacemakers or medical implants should not access to the region of 5G zone.
b) Wear appropriate PPE as required. Safety goggles and thermal insulated gloves must be worn if handing of cryogen is needed.
c) Objects should be tested for magnetic properties, if necessary, by a small hand-held magnets before being brought into a magnet room.
d) Remove all the metallic or ferromagnetic materials (coins, cell phones, watches, credit card, spatulas, stirring bar, hair accessories etc.) and stored in the designated plastic cabinet or box outside the 5G zone or outside the magnet room.
e) Switch on the ventilation system before operating the equipment to reduce the risk of asphyxiation.
f) Ensure warning signs are displayed at entrances to prevent entry by unauthorized personnel.
g) Ensure there is no metallic or ferrous tools such as screwdrivers, wrenches, tweezers stored in the magnet room.
h) Remember to use non-magnetic stainless dewars when transferring cryogens to the equipment.
i) Check the cryogen level and replenish if necessary to avoid magnet quenching. It is best practice to maintain a schedule for replenishment of cryogens.
j) Avoid positioning your head over the helium and nitrogen exit tubes.
k) Maintenance and repair work on equipment should be performed only by certified personnel.

In case of planned quenching for the reason of maintenance or repairing of equipment, the Laboratory Person In-Charge concerned should notify HKSTP in advance for necessary arrangement to prevent accidents or other adverse consequences.

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6. Emergency

Laboratory Persons In-Charge should address the potential hazards of MRI and NMR equipment and their corresponding safety measures to all concerned laboratory personnel. Suitable preparedness and arrangements should be in place to ensure that all laboratory personnel take appropriate actions in case of emergency.

a) In the event of quenching:

   i. Alert other personnel to evacuate the room.

   ii. Activate the emergency alarm and emergency ventilation system (buttons located near the entrance).

   iii. Leave the room immediately.

   iv. Report the incident to HKSTP for assistance following the “General Laboratory Emergency Procedures” in the SHE Handbook of HKSTP.

   v. Do not re-enter the room until the purge is complete and fresh air has been provided.

b) In the event of skin contact and eye exposure to cryogens:

   Follow the procedures laid down in the “Safe Handling of Cryogens” in HKSTP’s SHE Handbook.

c) In case of any metallic objects strike the magnet:

   Notify the Laboratory Person In-Charge immediately. Do not attempt to pull the object off yourself which may cause damage to the magnet and induce danger to yourself.