PENNSTATE

Environmental Health and Safety

# Superconducting Magnet Safety

Nuclear Magnetic Resonance (NMR) facilities present unique hazards not found in most laboratory environments. The NMR facilities maintain superconducting magnets which have a sustained field that is always present. A substantial inventory of cryogenic liquid is also present within the units.

## Facility design and installation:

Design and installation of a new NMR facility requires a number of safety considerations and it is essential to work closely with the manufacturers to identify issues associated with installation and operation. Temperature, structural support and magnetic field isolation should be considered in the design of and NMR facility. Successful operation of an NMR requires very tight temperature control. The higher frequency the NMR, the tighter the temperature control must be. An estimated +/- 1 to 2 degree Fahrenheit temperature control for a 300 MHZ NMR is suggested.

NMRs must also be installed in locations where magnetic fields do not create hazards for building occupants outside of the controlled ares.

The weight of an instrument is in the order of several tons which requires that it be placed in an area with substantial structural support. If the structural support includes steel beams or steel reinforced concrete, these ferromagnetic materials may have an effect on the magnetic field. The device should not be located near sources of RF such as heavy motors or relays.

Summary:

(1) Tight environmental temperature control is required
(2) Structural support for heavy equipment and vibration control is required
(3) Magnetic field isolation/control is required

## Magnetic field:

Magnetic fields can generate large attractive forces on ferromagnetic (metal) objects. Such objects include, most tools, gas cylinders, pocketknives, key rings, and most electronics. Any such object that gets too close to the magnet will be accelerated towards the magnet with great force. Metal belt buckles, steel tipped shoes, medical implants and any other metal on the person may be strongly attracted when close to the magnet. A best case scenario is simply lost time and expense of removing the object from the magnet. Larger objects (floor polisher for example) are troublesome and can seriously damage the magnet. Worst case is injury of the user or bystanders that could occur in two ways. First, an object pulled with great force towards the magnet could strike someone. Second, the object striking the magnet could cause the magnet to quench (i.e., become resistive). This vaporizes the magnets cryogenic cooling gases (helium, nitrogen), which will displace air in the laboratory. In this instance everyone must immediately leave the laboratory to avoid the potential for asphyxiation. Once energized the field of the superconducting magnet of the spectrometer is always present. These magnetic fields propagate horizontally and vertically. These fields extend outside the magnet; therefore, no movable metal objects should be allowed within the danger area of the instrument.

The generally accepted safe field is 5 gauss. It is good practice in NMR laboratories to indicate the 5 G magnetic field line (e.g. tape on the floor around the magnet). Magnetic fields may affect certain heart pacemakers. Demand-type pacemakers may be switched to basic rate pacing. Persons fitted with pacemakers should not be permitted in the area. The stray field of the NMR magnetic is well characterized by the vendor. Metal and instrumentation should all be outside this line. The control unit for the NMR where operators are located should also be outside the 5 Gauss threshold. It is necessary to use steel tools for maintenance and repair of the consoles, but such work should only be done by the NMR staff (or engineers from the manufacturers) and users are not allowed near the magnet during such work. Where possible, non-magnetic tools should be used on the magnets themselves.

These risks are minimized by preventing access to the NMR rooms by anyone other than the NMR staff and trained users. Anyone else needing to enter the NMR rooms should only do so in the presence of one of the NMR staff. Combination locks should be reset regularly to prevent their codes becoming known by others. The NMR vendor should be required to inspect the space and approve your NMR laboratory plans prior to delivery and setup. Since the magnetic strengths of NMR magnetic vary substantially depending on their application, the 5 G line will vary from one field strength to another. In addition, new magnetic systems that are actively shielded have the 5 G line much closer the exterior shell, and in some cases, inside the exterior shell. The point is that no two NMR laboratories are the same.

For information only and not to be considered exact specifications, the University of California Santa Barbara website gave the following information for the 5 Gauss perimeter (both horizontal and vertical):

| **Operating Frequency** | **5 Gauss Threshold** |
|---|---|
| 200 MHz | ~ 1.5 Meters (5 feet) |
| 400 MHz | 2.2 – 2.8 Meters (7.2 – 9.2 feet) |
| 500 MHz | 2.8 – 3.6 Meters (9.2 – 11.8 feet) |

As in any laboratory, unauthorized personnel should not be permitted into the NMR laboratory. This should be clearly identified outside the laboratory. In addition, a sign should be posted outside the laboratory that indicates a magnetic field is present within the laboratory. The vendor often gives these signs upon request at no cost. Most vendors also have signs that indicate people with pacemakers or metal medical implants are not permitted in the laboratory. It is always good practice to educate non-users (other colleagues, administrative support, custodial services, etc) in the general area of the laboratory what is inside the laboratory so in the event of an emergency they posses basic information for their own safety or to inform others (emergency personal) of the possible dangers.

Summary:
(1) Limit access to laboratory to only qualified personnel
(2) People with medical implants should not be permitted in the laboratory
(3) No metal objects permitted within the danger of the magnetic field
(4) Post sign outside laboratory “Unauthorized personal not permitted”
(5) Post sign outside laboratory “High Magnetic Field”
(6) Educate others about the NMR that work in the general area
(7) Be aware of any metal object worn on your body
(8) Do not bring magnetic recording material near magnet (ATM, disks, etc)
(9) Minimize time within the 5 G line

<u>Cryogenic Liquid Nitrogen/Helium Fills</u>

Once operational the magnetic field does not turn off. To sustain the superconducting field cryogenic gases are used. The inner cooling gas is liquid helium with an outer dewar containing liquid nitrogen.

The main risks are burns when handling cryogens and asphyxiation if a magnet quenches. These risks are minimized by only allowing experienced individuals to fill the magnets with liquid nitrogen and liquid helium. Gloves, eye protection, and closed shoes must be worn during transfer. The expansion ratio of the gases can be used to determine the volume of helium or nitrogen gas that would be released if all the liquid in the NMR were to vaporize. This allows calculation of risk in case of a quench and necessary emergency exhaust ventilation requirements.

At least two staff should be present during refilling and appropriate safety clothing must be worn (gloves and eye protection). Refills must be continuously attended. It is particularly important that the person filling the magnet, once trained, should do so on a regular basis so as to be familar with the required routine. Magnet quenches (the rapid release of gaseous cryogens from the cryostat into the room) should trigger an alarm thereby preventing any risk of asphyxiation due to the large volume expansion.
In the event of a quench, personnel should evacuate the area (a quench warranting evacuation would be obvious by the noise of the escaping gas and clouds of vapor).

Access to the NMR rooms must be strictly limited to the NMR staff during refills and any major maintenance. During other periods access must be limited to a known set of users via combination locks. The magnet cryostats continuously expel a small quantity of gaseous He and N2 into the air. This does not present a hazard since during everyday use the air is constantly changed in the NMR rooms by the ventilation system. Any drop in the oxygen content of the air can be detected by oxygen monitoring. A site-specific operating procedure should be developed by the NMR staff for topping up of liquid cryogens. Even though magnetic quenching usually is very obvious, it is prudent to install an oxygen sensor in the laboratory that alarms when oxygen levels are approaching an unsafe level. Since the possibility of a quench is higher when filling the magnet, and since the transfer involves manual operations, there is a remote possibility that an operator could be rendered unconscious around the time of a quench. Fills should only be only done by a single operator when the fill cannot be deferred, and exceptional caution should then be used. Cryogen tanks on wheels must be secured around the magnet if used for filling operations.

Summary:

(1) Gloves, eye protection, and closed shoes worn during transfer
(2) Secure tanks during transfer
(3) Never leave the room until transfer is complete.
(4) The laboratory should be evacuated in the event of a quench
(5) It is prudent to invest in an oxygen sensor for your laboratory
(6) Always have more than one person in the area during fill
(7) Create a simple plan for personnel in unlikely event of quench

<u>Additional safety considerations</u>

Anyone working with the NMR should receive proper training. Training from the vendor is recommended for the person who will primarily be responsible for the NMR.

The magnet/dewar has a high center of gravity and could tip over if struck by a large object. In addition to serious injuries to persons near the magnet, the sudden release of nitrogen and helium gases from the dewar will displace breathable oxygen in the room. Support ropes, bolting to the floor, or other methods should be used to stabilize the magnet.

Do not exceed the boiling or freezing points of the test sample. A sample subjected to a temperature change can build up excessive pressure which can break the tube. Broken glass, projectiles and hot or toxic chemicals can cause injury. To avoid this hazard, establish the freezing and boiling points of a sample before doing a variable temperature experiment, and never rapidly heat or cool a sample. Always wear safety glasses near the magnet when performing variable temperature experiments.

Be very careful with sample tubes as they are fragile and break easily. The top of the sample tube can break off when the probe is removed. The sample should be ejected before removing the probe from the magnet. Use extreme caution when removing the probe if the sample cannot be ejected.

Do not operate NMR spectometers in the presence of flammable gases or fumes. Flammable gases or fumes create the risk of injury or death from inhalation, fire and explosion.

Do not look down the upper barrel of an NMR spectrometer if a probe is in place. Pneumatic ejection of a sample from the probe due to pressure buildup could cause injury.

Electrical and radio frequency risks are similar to those encountered in the use/maintenance of other laboratory equipment and are minimized by restricting any modification/maintenance of the equipment to the NMR staff (or very experienced users) in consultation with the manufacturer.

Only carbon dioxide fire extinguishers should be used to avoid equipment damage and exceptional care is needed to ensure that fire extinguishers are not used near the magnet cryostat. In case of serious flooding, or in other situations where there is risk of electrocution, the equipment circuit breakers should be turned off.