Safety Matters

For laboratory cryogenic and high field magnet systems

IMPORTANT: This Handbook contains important safety information – use of these systems without observing this information is dangerous and could result in death or serious injury.

- **This Handbook is written in the English language. You must ensure that the persons using these systems understand the English language or alternatively ensure that they receive the information contained in this Handbook in a language which they understand.**
- 本手册为英文版本。
  必须确保系统的使用者能够理解英语或者他们可以其明白的语言获得本手册中的相关信息。
- **Ce manuel est écrit en Anglais. Vous devez vous assurer que les personnes utilisant ces systèmes comprennent l'Anglais ou alternativement vous assurer qu'ils reçoivent l'information contenue dans ce manuel dans une langue qu'ils comprennent.**
- **Dieses Handbuch ist auf Englisch geschrieben worden. Sie müssen sicher sein, dass die Anwender der Systeme die englische Sprache beherrschen. An sonsten müssen Sie dafür sorgen, dass den Anwendern die im Handbuch enthaltenen Informationen auf eine ihnen bekannten Sprache zur Verfügung gestellt wird.**
- ”このハンドブックは英語で書かれております。該当装置を使用する方は、英語を理解できる必要があります。あるいは、このハンドブックに書かれている内容を、使用者が理解できる言語で書かれた物を用意してください。”
- **Questo manuale é in lingua Inglese. É necessario assicurarsi che chiunque utilizzi questi sistemi comprenda l'inglese o, in alternativa, riceva le informazioni contenute nel manuale in un linguaggio conosciuto.**
- **Este manual está escrito en Inglés por lo que deben asegurarse de que las personas que usen estos sistemas entiendan el idioma Inglés o por otra parte asegurarse de que reciban toda la información contenida en este manual en el idioma que ellos entiendan.**

- **Do not use or allow others to use these systems unless they have first read this Handbook.**
- **Do not use or allow others to use these systems without proper training; this Handbook is not a substitute for training.**
- **This Handbook is written for users who are technically trained to work in a laboratory environment and with equipment of this nature; persons who are not so trained should not use the equipment.**

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Warning This booklet contains essential safety information and warnings which could help you to reduce the risks when you are using a cryogenic or high magnetic field system supplied by Oxford Instruments NanoScience. Make sure that no one is allowed to use the system without reading the relevant parts of this booklet.

See page 8 to find out which parts you need to read.

Scope The booklet covers the hazards that you could commonly encounter with liquid helium and liquid nitrogen cryostats, the vacuum systems associated with them and superconducting magnets supplied by Oxford Instruments NanoScience. It does not describe the law for any country, does not cover cryogens other than liquid nitrogen and helium and is not intended for large scale installations.

Training Proper training by a competent person with local knowledge is essential because all cryogens are potentially hazardous; this booklet is not a replacement for such training.

Note Please note and observe any warnings and instructions in this booklet, and the Operator's Handbook (which may contain specific warnings and procedures for your system). These documents are essential parts of the system and should be kept with the system for the whole of its life (even if you sell or give it to someone else).

Disclaimer Although every effort has been made to ensure that the information in this booklet is accurate and up to date, errors may occur. Oxford Instruments NanoScience shall have no liability arising from the use of or reliance by any party on the contents of this booklet and, to the fullest extent permitted by law, excludes all liability for loss or damages howsoever caused.

However, if you find any errors or omissions or have any other suggestions please tell us about your experiences so that we can continue to improve this booklet. Your experiences may help others.

Part number USC0001

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1. Introduction

Oxford Instruments NanoScience designs and builds cryogenic systems that are safe to use. However, it is important that when using our equipment you are aware of the potential hazards posed by liquid nitrogen, liquid helium and high magnetic fields. As most users are accustomed to working in a laboratory environment and want to know the reasons for the recommended procedures this booklet tries to outline the most common hazards in appropriate technical terms.

Everybody who operates the system should read and understand this booklet, not just senior staff. Keep it close to your cryogenic system and use it to remind yourself about the correct procedures. There are other very good books on the subject of safety and these should be used. One example is *Cryogenics Safety Manual - a guide to good practice*[1].

All cryogens are potentially hazardous but knowledge of their properties will help you to understand why precautions are necessary. Liquid helium and liquid nitrogen are less dangerous than some other cryogens because they are neither poisonous nor flammable.

It is not worth taking the risk of ignoring the advice in this document. For example, even small cryogenic burns are extremely painful and take a long time to heal. If you are not so lucky, you may be blinded or even killed, so think carefully.

If you are already skilled in the use of cryogens and high magnetic fields you may feel that it is safe to use your professional judgement and decide not to follow all of the recommended procedures. Your knowledge of the signs which indicate that a hazard is developing may help you to avoid most of the risks. However, other less-experienced people around you may not understand these signs and they may be tempted to follow your example.

Please note:

- If the equipment is not used in the manner specified by Oxford Instruments NanoScience then the protection provided by the equipment may be impaired.
- The equipment is not suitable for use with explosive or flammable gases.
- The equipment is not suitable for use in explosive, flammable or other hazardous environments.
- Maintenance: only qualified and authorised persons should carry out servicing and repair work on this equipment.
- Only use genuine Oxford Instruments NanoScience spare parts. Contact OI Direct or Oxford Instruments NanoScience Customer Support to obtain these[2].

1.1. Conventions used throughout this booklet

The following general symbols are used throughout this booklet to draw special attention to the most important messages. Other, more specific, symbols are used in certain cases. However, the paragraphs which are not marked with a symbol should still be read carefully as they either describe additional rarer hazards or give further explanations.

The yellow warning triangle highlights dangers which may cause injury or, in extreme circumstances, death.

The text explains the hazard and the correct procedure. The warning triangle may be followed by specific symbols and instructions.

A white symbol in a blue circle indicates something that you must do.

The general caution symbol highlights actions that you must take to prevent damage to the equipment.

This symbol indicates that loose fitting, insulating gloves should be worn, suitable for protection against splashes of liquid helium and nitrogen.

This symbol indicates that protective goggles or (for cryogenic use) a face mask should be worn.

This symbol indicates an asphyxiation hazard.

This is the symbol for protective earth.

Copies of many of the above notices may be obtained from OI Direct[2].

1.2. The sections you should read

It may not be necessary for you to read the whole of this booklet, since it is designed to cover a wide range of products. This page should help you to find out the parts that are relevant to you. Before you start to use any cryogenic or vacuum equipment you should be properly trained by a competent person. Contact your Safety Officer, arrange for the necessary training and then use this booklet as a summary of the hazards you are most likely to encounter. Remember that it is your responsibility to ensure the safety of all personnel, equipment, services or data links in or near your laboratory.

If you are setting up a laboratory
If you are designing a new laboratory or planning to install new equipment in an existing laboratory then section 1.5 will be useful.

If you are using a cryogenic system (without a magnet)
If you are using a cryogenic system (without a magnet) it is important that you read the following sections which give you advice on the essential safety procedures:

Section 1.3	Common hazards in cryomagnetic laboratories
Section 2	Using vacuum and high pressure systems
Section 3	Operating cryogenic systems
Section 5	Working with electrical equipment

If your system is too heavy to lift by hand you should also read section 6 which explains how to lift heavy systems safely.

If you are using magnetic field systems
If the system you are using contains a magnet it is important that you read all sections listed above and:
Section 4 Superconducting magnet systems

If you are using a nuclear orientation thermometer
The procedures for using a low activity cobalt-60 (^{60}Co) gamma ray source are given in section 7.

1.3. Common hazards in cryomagnetic laboratories

The following list shows the range of hazards that you may encounter when you are using laboratory scale cryostats. You can protect yourself against all of these hazards by following the procedures described in this booklet, supplemented by any material in your Operator's Handbook.

- Extreme cold and the consequent risk of cold burns or frostbite
- Asphyxiation (if the atmospheric oxygen is displaced)
- Fire and explosion hazards (through oxygen enrichment)
- Magnetic fields effects on medical implants
- Large attractive forces between the magnet and other magnetic objects
- Electrical hazards (including high voltage hazards)
- Vacuum hazards
- High pressure hazards
- Radioactive contamination from nuclear orientation sources used as thermometers
- Damage or injury caused by lifting heavy equipment using incorrect procedures.

If you suspect that there is a fault with your system (perhaps indicated by one of the following signs) cease your experiment and use of the equipment immediately. Take immediate action to repair the fault (if you know how to do this) or close down the equipment and have it attended by an appropriately qualified person.

Signs that a hazard might be developing:
- Unusually high (or low) cryogen evaporation rate
- Unusual condensation of atmospheric moisture on to any part of the cryostat
- Unexpected patches of ice on any part of the cryostat
- Difficulty in opening or closing any of the valves.

The Operator's Handbook for your system may give additional information about hazards not covered by this booklet, and specific procedures to follow.

If you are in doubt about any aspect of the operation of the system you should contact a local expert or your supplier. If you sell or give your system to someone else you are obliged to warn them in writing about the potential hazards and you may like to use this booklet to do so.

1.4. Working alone

Do not work alone. It can be dangerous. If you have an accident there will be no one there to help you.

If, despite this warning, you have decided that it is worth taking the risk then arrange to call someone regularly to confirm that you are safe. If they do not receive your call at the expected time they can then investigate.

1.5. Setting up your laboratory

When you are setting up your laboratory you should:

- Design the laboratory with safety in mind.
- Consult an expert who has experience of setting up other similar laboratories.
- Set up procedures to be followed by anyone using the equipment.
- Make sure that the correct procedures and local regulations are always followed.
- Train all personnel and supervise them properly.
- Display clear notices to warn people that they are entering a potentially hazardous area. Remember that even if the door is locked, some other people have keys. For example, cleaners and security staff are often working when there is no one else around; they are at risk too.
- Tell the local Safety Officer about your system and ask them to make local emergency services aware of the hazards, as this may affect the procedures they follow when they are dealing with fires or other incidents.
- Consult your local fire authority about the equipment you should install in case of a fire. They may require that portable fire fighting equipment is non-magnetic. Ask them to check whether your smoke detectors will be set off by helium gas (as some are).
- Consider carefully whether the floor in your laboratory is strong enough to take the weight of the system. Seek professional advice if necessary[6].
- If you are using a superconducting magnet system, consider whether there are any large magnetic items close to the system (such as magnetic beams in the floor). Check whether the stray field will affect other equipment or people in your laboratory or in other rooms nearby (even on other floors)[6]. Use the information in your stray field map and the guidelines in section 4.3.
- Install an overhead crane (or other lifting equipment) capable of lifting your equipment safely.
- Make sure that the material of the floor will not be damaged (or become hazardous) if cryogens are often spilt on it.
- Position the system so that it is not necessary to pass the cryostat in order to reach a safe exit point.
- Provide suitable venting for exhaust gases (section 3.6).
- Make sure that the laboratory is sufficiently well ventilated; this is discussed in detail in section 3.6. If there is any doubt, install sensors which will warn you if the oxygen level becomes dangerously low (less than 18%). Fixed and portable oxygen monitors are readily available[2] (see also section 3.1). Helium gas tends to collect near the ceiling whilst cold nitrogen gas tends to collect near the floor; you are therefore advised to fit one monitor at a high position and one low.
- Provide an earthing point to be used to connect an earth cable to the cryostat; this is especially important for systems with superconducting magnets that are not earthed via the magnet power supply.
- Provide appropriate first aid equipment.
- Refer to relevant local health and safety publications.

If you require advice or want a formal site survey you should contact the Helpdesk at Oxford Instruments NanoScience[3].

2. Using vacuum and high pressure systems

2.1. Vacuum pump operation

If rotary pumps are operated without good oil mist filters, they emit a mist which represents a health hazard. Do not breathe these fumes. If a suitable filter is not available the exhaust from the pump must be piped outside the building.

2.2. Vacuum vessels and overpressure

Vacuum spaces in cryogenic systems must be protected with an overpressure relief valve.

If a system is operating for an extended period a small air leak may go unnoticed. The air that leaks into the vacuum space will freeze on to any cold surface or be absorbed on to a sorption pump, if fitted. Only when the system is warmed up does it become apparent that a large quantity has been collected; this may expand to fill the vacuum space to a pressure higher than it can safely withstand.

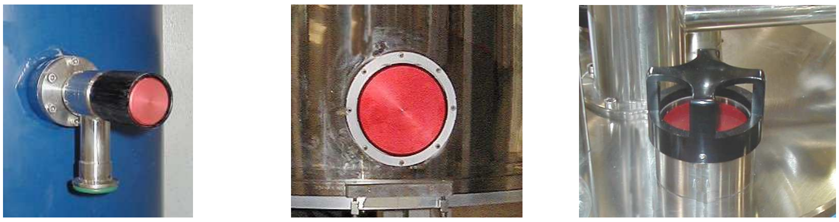


Figure 1 Examples of Oxford Instruments (red) over-pressure relief mechanisms

Another hazard occurs if one of the vessels filled with cryogenic fluid becomes damaged, when the fluid may be released into the vacuum space, where it breaks the vacuum and is rapidly warmed.

To protect against both eventualities suitable relief valves are required on the liquid and vacuum spaces to vent the gas generated; all Oxford Instruments NanoScience systems are protected in this way.

2.3. Vacuum vessels and collapse

Do not evacuate vessels unless they are designed to work under vacuum. Vent evacuated vessels slowly.

Some systems may be damaged if you allow the pressure in a vacuum space to rise too quickly. The shock of the sudden pressure increase may cause an otherwise safe tube to collapse. Some systems must be vented slowly to allow the pressure to equalise in different parts of the system.

2.4. High pressure cylinders

You must determine local laws and regulations relating to high pressure cylinders and follow them.

High pressure cylinders are commonly used to store gases, at pressures up to 200 bar. Most countries have laws about using them. Helium and nitrogen gas are the most common requirements for cryogenic laboratories.

- Store upright and secure at all times to prevent them falling. They must never be left free-standing.
- Store cylinders where they are not at risk from accidental damage.
- Move cylinders by means of a purpose-designed trolley in the upright position with the valve closed and the regulator and other equipment removed. Cylinders must never be rolled along the ground on their side.
- Only use a regulator that is designed and labelled for use with the gas in the cylinder.
- Cylinders must be labelled with the contents, pressure, size and safety information.
- Store cylinders where the magnetic field is below 10 gauss.

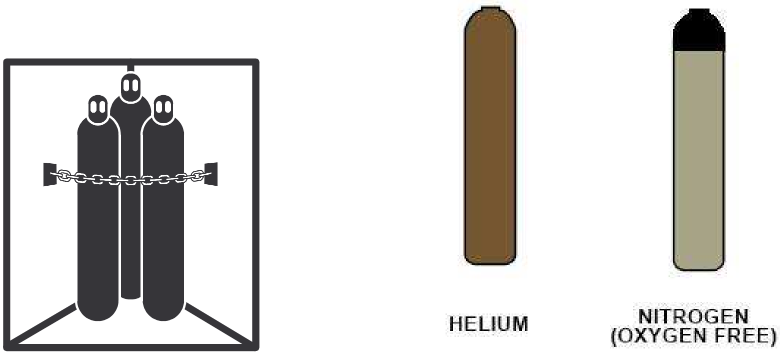


Figure 2 Cylinder security and EU colour codes for helium and nitrogen cylinders

High pressure cylinders become dangerous projectiles if they are ruptured or the valve is knocked off, and they can break through thick walls or travel hundreds of metres (by rocket propulsion).

3. Operating cryogenic systems

When you are handling cryogens you have to protect yourself and others from the potential hazards. Make sure that you know enough about their properties and use them appropriately.

In particular, you need to protect yourself from:

- Extreme cold
- Asphyxiation
- Fire and explosion hazards
- Hazards associated with vacuum systems used to contain cryogens; these have been discussed in section 2.

You can protect yourself from the extreme cold by wearing suitable clothing but you can only protect yourself against the other hazards by making sure that they do not occur.

Fit clear labels to cryogenic vessels to indicate their contents. This helps other people to decide what precautions they need to take to ensure their own safety. Remember that it is your responsibility to keep the working environment safe for other people and they may hold you liable if you do not.

Your system will be fitted with one or more safety devices. These are coloured red and should never be modified or obstructed. Examples are shown in Figure 1, Figure 11 and Figure 16.

If a safety device operates (opens) it may vent quantities of cold gas. Laboratory activities must be regulated to allow for this possibility.

3.1. Personal protective equipment (PPE)

Personal protective equipment is readily available and should be used (Figure 3).

- Wear a face shield or goggles to protect your eyes. Eyes rarely heal well!
- Use cryogenic gloves if there is any danger of touching cold metal; these should be loose fitting so that you can remove them easily. If you are transferring small quantities of liquid nitrogen and there is no danger of touching cold metal then it is usually safer not to wear gloves.
- Wear overalls or similar clothes without pockets or turn-ups.
- Wear a cryogenic apron to protect against spills. Cryogens have low viscosity and penetrate clothing much faster than water.

- Wear sensible shoes (not sandals) and make sure that your trousers cover the top of your shoes to prevent spilt cryogens running into them.

Figure 3 A full set of PPE including cryogenic apron and gloves and face mask[2]

In the event of liquid nitrogen being splashed onto your bare hands accidentally, spread your fingers as you move your hand away. This will help to prevent cryogenic burns caused by droplets of the liquid being trapped between your fingers.

Even if you try to push or throw away a very cold object with your bare skin it could stick to you (by rapid freezing of local moisture) and tear away the skin. Do not underestimate the speed with which this freezing process can occur.

3.2. Storage, transport and handling cryogens

Store and transport cryogens using only the containers for which they were specifically designed. For examples see Figure 5 and Figure 8.

Store and transport cryogenic vessels in an upright position. Internal support is generally restricted to the region at the top of the neck tubes and the system may be easily damaged by tipping the vessel away from vertical.

- Storage and transport vessels must be made of suitable materials. Many materials (even some common steels) become dangerously brittle at low temperatures.
- Bungs (or stoppers) should be tied to the top of the container. This prevents them from being lost and ensures that they cannot be blown out by high pressure and become dangerous projectiles.
- If you are using a magnet system, the cryostat and transport vessel should be constructed of non-magnetic materials.

Figure 4 Operator is protected from cold helium gas by gloves and face mask

3.3. Avoid spillage of cryogens

Spilt cryogens will dramatically reduce the temperature of the item on which they are spilt; this may affect it in many ways.

- Cryogens spilt on vacuum equipment may freeze rubber vacuum seals (such as 'O' rings) and cause loss of insulating vacuum. Route transfer lines away from vacuum seals and use a hot air blower if ice starts to collect.
- If you spill cryogens on electrical cables they may freeze and fracture the insulating layer causing electrical hazards. Keep all cables above the level where cryogens may be spilt on them, not on the floor.
- Spilt cryogens can also condense the moisture from the air to form a thick mist which can obscure your vision. If you are enveloped in a cloud of cold gas you may lose your balance and fall. This is particularly dangerous if you are standing on a platform.
- The floor of your laboratory may be damaged if cryogens are spilt over it. In particular, plastic tiles may become very brittle or may be cracked by rapid cooling.

3.4. Liquid nitrogen - specific techniques

Liquid nitrogen should not be stored in open topped dewars as it would then be exposed to air. Since liquid oxygen has a higher boiling point than liquid nitrogen, oxygen from the air will then condense into the nitrogen. If this is allowed to continue, the oxygen concentration may become so high that the liquid becomes as dangerous to handle as liquid oxygen. This applies particularly to wide-necked dewars.

Open dewars should at least be covered with the lid provided to minimise contact with the air.

Figure 5 Examples of open and self-pressurising liquid nitrogen storage vessels[2].

Liquid nitrogen can be poured from small vessels using a funnel or tipping trolley. If the storage dewar is too big to be tipped over, or if it might be damaged, the liquid can be transferred by pressurising the storage dewar using helium or nitrogen gas but not air.

Figure 6 Examples of tipping trolleys for liquid nitrogen[2].

Only use suitable metal tubing to transfer cryogens. Do not use rubber, silicone rubber or plastic tubing.

Although polythene and nylon are sometimes used this should not be taken as a recommendation. Any materials you decide to use should be carefully tested in safe conditions, and only used if approved by the manufacturer.

Uninsulated transfer lines can be used but losses should be expected and there are potential fire hazards associated with oxygen enrichment around the tube (section 3.7).

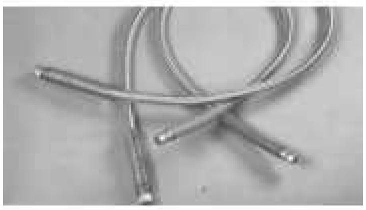


Figure 7 Stainless steel transfer lines for liquid nitrogen[2].

Remember that inserting a warm tube into a dewar of liquid nitrogen will cause cold gas (and possibly liquid) to be ejected from the open end.

Make the following daily checks on liquid nitrogen vessels:

- Check the boil off and investigate if it is higher or lower than expected
- Check the liquid level and refill if necessary
- Check that the relief valves have not been tampered with
- After a liquid helium transfer into a liquid nitrogen shielded helium vessel, check that the nitrogen vents are still clear (Figure 13).

3.5. Liquid helium - specific techniques

Liquid helium may cause blocked vents or oxygen enrichment.

Liquid helium is the coldest of all cryogenic liquids. It will therefore condense and solidify any other gas coming into contact with it. Any surfaces cold enough to condense air in normal operation could also increase the oxygen concentration to a dangerous level. You must remove all traces of combustible materials ("oxygen clean").

Clean to "oxygen clean" standards any surface cold enough to condense air in normal operation.

This also explains why liquid helium containers often have labels saying "Flammable liquid" even though the liquid is not flammable.

Because of its low boiling point and low latent heat liquid helium can only be transferred from vessel to vessel using specially designed, vacuum insulated metal transfer tubes such as the one shown in Figure 3. Techniques for using these will be described in your Operator's handbook.

Figure 8 A typical liquid helium storage vessel.

Do not transfer liquid helium from vessel to vessel except with a specially designed transfer tube.

Insert warm objects into liquid helium vessels very slowly.

This makes sure that they are well cooled by the cold gas before they reach the liquid and:

- Reduces the hazard from rapid boiling which produces a jet of cold gas.
- Considerably reduces the consumption of liquid, saving money.

Remember that inserting a warm tube into a dewar of liquid helium will cause cold gas (and possibly liquid) to be ejected from the open end.

Liquid helium must be kept in specially designed storage or transport vessels.

Dewars should have a non-return valve fitted in the helium exhaust line at all times or be connected to a helium recovery system, so that air does not enter the neck and block it with ice.

If possible, liquid helium should be kept at a slight positive pressure, so that if there is a leak, helium may leak out but air does not leak in.

Make the following daily checks on liquid helium vessels:

- Ensure that the non-return valve (or recovery system) is still fitted to the exhaust.
- Check that all other ports on the top plate are sealed properly.
- Check the boil off and investigate if it is higher or lower than expected.
- Check the liquid level and re-fill if necessary.

3.6. Protection against asphyxiation

Atmospheres containing less than 18% oxygen are potentially dangerous and entry into atmospheres containing less than 20% is not recommended.

Figure 9 Typical portable oxygen monitor

Asphyxia due to oxygen deficiency is often rapid with no prior warning to the victim. **There is no sensation of breathlessness to warn you that you are being asphyxiated**; breathlessness is a symptom of a high concentration of CO_2 not a low concentration of oxygen. A general indication of what is liable to happen in oxygen deficient atmospheres is given in the next table[4] although the reactions of individuals can vary widely.

Oxygen content (vol %)	Effects and symptoms (at atmospheric pressure)
11 – 14	Diminution of physical and intellectual performance without the person's knowledge.
8 – 11	Possibility of fainting after a short period without warning.
6 – 8	Fainting within a few minutes; resuscitation possible if carried out immediately.
0 – 6	Fainting almost immediate; death ensues; brain damage even if rescued.

Table 1 Guide to stages of asphyxia

The victim may well not be aware of the asphyxia. If any of the following symptoms appear in situations where asphyxia is possible and breathing apparatus is not in use, immediately move the affected person to the open air, following up with artificial respiration if necessary:

- Rapid and gasping breathing
- Rapid fatigue
- Nausea
- Vomiting
- Collapse or incapacity to move
- Unusual behaviour

It is important to make the relevant preparations before you put yourself at risk. If the oxygen level is being reduced slowly the first symptoms may be increased pulse and breathing rate with impaired judgement, but the very first symptom you notice may be that you cannot stand up or even crawl. By this stage it is already too late for you to help yourself.

Protect yourself against asphyxiation as follows:

- Ensure that there is sufficient ventilation in your own laboratory and in other rooms nearby.
- Install sensors which will sound an alarm if the oxygen level is too low unless you are sure about the effectiveness of the ventilation in a room. Inexpensive, portable oxygen monitors are readily available[2] (Figure 9).
- Leave the room immediately if a large amount of cold gas is released quickly (for example after a superconducting magnet has suddenly become resistive or "quenched", releasing its energy into the liquid helium). This is discussed further in Sections 4.6.
- Ventilate the room well if you are precooling a large system with liquid nitrogen.
- Leave the room immediately if a large amount of liquid is spilt. Consider sounding the fire alarm if there is likely to be a fire hazard, or to clear the area quickly.
- If there is a possibility of a lack of oxygen in the room, hold your breath, to remind yourself of the urgency of leaving the area.
- Do not accompany storage or transport vessels in confined spaces (especially in lifts, elevators or enclosed vehicles).
- Use a suitable exhaust system to pipe exhaust gases away from the cryostat to the atmosphere or into a recovery system. This needs to be designed by a competent engineer.
- If you store cryogenic liquid vessels in a room that is not well-ventilated, put warning signs on the doors so that no one enters the room until it is well ventilated. The room should be locked and the oxygen concentration must be checked before anyone enters the room.
- Remember that cold nitrogen gas tends to collect near the floor, and helium gas near the ceiling.

Ensure that oxygen monitors are calibrated regularly according to the manufacturer's instructions.

Calculate possible oxygen depletion following a spillage

Part of the risk assessment process should consider the worst case scenario when the entire contents of a cryogenic storage vessel are lost to the room. For example, a dewar of volume V_D (m^3) is filled with a cryogenic liquid with gas to liquid ratio f (see Appendix A Properties of helium and nitrogen). If you assume 10% filling losses then the total volume of gas lost to the room is

$$1.1 \times V_D \times f \quad m^3$$

If the volume of the room is V_R then the oxygen percentage may be reduced from 21% to

$$21 \times (V_R - 1.1 \times V_D \times f)/V_R \quad \%$$

Example: The room is 7 x 8 x 2.5 metres (140m^3). A 25 litre dewar of liquid nitrogen has just been filled. If the entire contents are spilled the oxygen concentration is reduced to

$$21 \times \left(140 - (\frac{1.1 \times 25 \times 694}{1000})\right)/140 = 18.1\%$$

The room is just big enough.

Ventilation
The type of ventilation depends on a multitude of factors such as type of location, gas type, possible leaks etc.

Ventilation can be natural or forced. The design criterion is the number of air changes per hour. In locations above ground level with no special ventilation openings natural ventilation will provide typically 1 change per hour. This is not the case in buildings with windows that are tightly sealed. For underground rooms with small windows 0.4 changes per hour can be considered as an average value.

Natural ventilation is generally sufficient for handling transportable cryogenic vessels above ground level, provided that the room is large enough or that any outdoor area is not enclosed by walls.

An indoor area should have ventilation openings with a total area of 1% of the ground area. The openings should be positioned diagonally across the room. The density of the gas should also be taken into consideration with the main opening at the highest point for gases lighter than air (e.g. helium) and at ground level for gases heavier than air (e.g. cold nitrogen).

To achieve more than two air changes per hour a forced ventilation system is necessary. Different regulations may recommend or require for different situations a specific number of air changes per hour.

Any laboratory area below the normal floor level (such as a pit) can easily become enriched with nitrogen; such an area must be regarded as a special hazard and restricted accordingly.

3.7. Protection against fire hazards

Oxygen enrichment may cause spontaneous combustion.

Most of the fire hazards encountered in normal laboratory scale cryogenic systems are caused by oxygen enrichment. Liquid oxygen can condense from the air on to surfaces which are at temperatures below 90 K. You can often see liquid air running from a cold helium recovery line if a helium transfer is carried out too quickly or if a magnet has quenched (Figure 10). This liquid can promote fires, even with materials that normally might not be regarded as combustible.

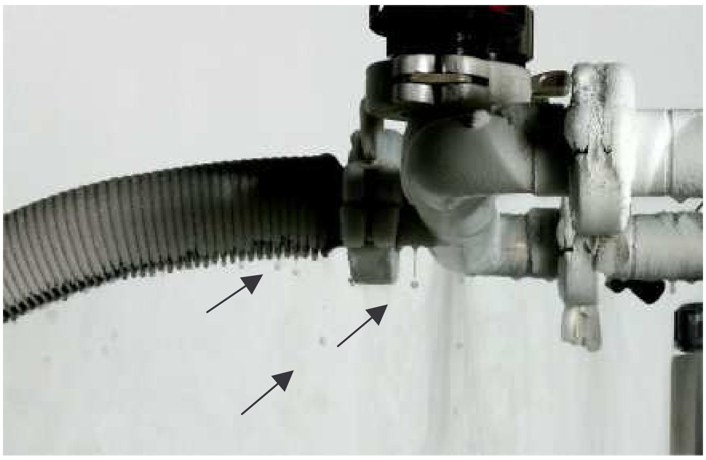


Figure 10 Drops of oxygen-enriched liquid air (~50% oxygen) condensing from the atmosphere

Liquid nitrogen in an open bucket tends to condense atmospheric oxygen into solution because the boiling point of oxygen is above that of nitrogen. In equilibrium, the liquid may have an oxygen concentration higher than 50%. Any combustible materials exposed to this liquid can burst into flames spontaneously. A foam plastic bucket containing liquid oxygen presents a serious hazard.

Liquid air and liquid oxygen *can* be handled safely, but only by those who have had the necessary training.

If you transfer liquid nitrogen through a tube that is not vacuum insulated, remember that oxygen enrichment will occur around the outside of the tube. Any flammable lagging material that comes into contact with this liquid (e.g. cloth or polystyrene) could burn fiercely if it is accidentally ignited. Some materials even ignite spontaneously in liquid oxygen!

Avoid the risk of fire by taking the following precautions:

- Make sure that there is no oil or grease in a position where it may be exposed to liquid air (even if it is liquefied by accident).
- Do not use compressed air to blow liquid nitrogen out of a cryostat because the oxygen in the compressed air will condense into the liquid very easily.
- Forbid smoking in the areas where cryogens are handled.
- Make sure that suitable fire extinguishers are available; CO_2 extinguishers are normally recommended.
- Train people to use the fire extinguishers properly.

If a fire breaks out, sound the fire alarm and make sure everyone leaves the area.

Special expertise is required to put out these fires safely so if you have not been trained how to do it find someone who has. If you choose the wrong type of fire extinguisher or you do not use it properly you may block the exhaust vents of the cryostat with ice. Blockages are discussed in the next section.

After the fire has been extinguished make sure that the system is safe.

3.8. Protection against blockages and their consequences

These guidelines are intended to apply only to preventing rupture of a cryogenic vessel caused by accidentally blocking the exhaust or warming up a cryostat which has accidentally condensed contamination from the atmosphere on to cold surfaces. This should be sufficient for most laboratory systems. Flammable or explosive cryogens which are likely to cause explosions because they have caught fire are not covered by this booklet.
Symptoms of a partial or total blockage include:

- Abnormally low or high cryogen evaporation rate.
- Difficulties in removing ancillary items such as demountable leads or transfer syphon
- Inefficient helium transfer.

Blockages are frequently caused through leaks past cracked or badly seated ‘O’ rings or by poor cryogenic practice such as leaving cryogenic vessel necks open to the atmosphere.

If the exhaust ports are connected to pumping lines or a helium recovery system, make sure that the lines have a large enough diameter for the expected gas flow. In general, you should assume that the diameter of the tube must never be smaller than the diameter of the exhaust port.

The helium reservoir exhaust must be fitted with a non-return valve or connected to a helium recovery system.

This prevents ambient air leaking back into the cryostat. The valve should be at least large enough to handle the normal gas flow during a liquid helium transfer.

Systems must be fitted with pressure relief valves to allow helium and nitrogen gas to leave the system quickly. If your system was fitted with one of these valves when it was supplied, it must never be cooled down without it.

In the event of a magnet quench or major vacuum failure the evaporated helium will be vented safely through the valve(s). Various pressure relief valves are illustrated in Figure 11, Figure 12 and Figure 16 (right).

Figure 11 A pair of pressure relief valves fitted to an Oxford Instruments NMR system

All relief valves on the system should be large enough to handle the maximum possible gas flow, caused by all possible failure modes happening together.

Rapid failure of the insulating vacuum can cause all the liquid in the cryostat to evaporate very quickly.

Make sure that all exhaust vents are kept clear of ice.

If possible, arrange for the vents to be at a temperature higher than 0 °C, so that water does not freeze there. You can sometimes do this by fitting a short length (say 20 cm) of plastic pipe over the vent tubes; they will be covered with ice but if they are long enough the open end will be warm enough to stay dry. Make sure that systems are not stored where they might be exposed to rain or moisture, unless they are properly protected.

Check for blockages regularly and often as shown in Figure 13.

Check the system boil off regularly. If there is no boil off and you know that the system is not empty check whether a blockage is preventing the natural boil off. The pressure inside the cryostat may rise until it reaches a dangerously high level. Always fit a non-return valve such as in Figure 12 to at least one of the liquid nitrogen vessel ports. "Bunsen valves" (which are sometimes recommended for this application) are a crude form of non-return valve made from rubber tube. Do not rely on them to protect a vessel effectively because they do not seal well, especially when frozen.

Even after all the liquid has evaporated there should still be a perceptible flow of exhaust gas as the gas in the system warms up. In other words, even if the system contains no liquid it is not “empty” or safe until it reaches ambient temperature.

Figure 12 Pressure relief valve for nitrogen vent ports on standard Oxford Instruments cryostats

3.9. Clearing blocked tubes

If you find that all the vents of a vessel are blocked, you should quickly and calmly evacuate the area and then find an experienced cryogenic technician to help you clear it.

The expert will be better qualified to decide how much time to spend trying to clear the blockage before it is too dangerous to be near the cryostat. If only one vent is blocked and the vessel is still venting safely through another vent, it may not need urgent attention but you should still clear the blockage as soon as possible.

If the vent has been blocked for an unknown length of time or if you cannot clear the blockage, consider moving the vessel to a safe place. Evacuate everyone from the area, and do what you can to reduce the secondary risks from the effects of possible rupture of the vessel.

If you cannot find an expert you are advised to contact Oxford Instruments NanoScience Customer Support before trying to clear it yourself. They will be able to provide detailed advice. For instance, if the magnet is in persistent mode at field you will have to balance the risks associated with running the magnet to zero (which increases the helium boiloff during the ramping process) with the risk of damaging the magnet if it warms sufficiently to quench.

Unblocking procedures require a supply of helium gas at room temperature or a warmed copper or stainless steel tube or a combination of both.

Remember that the process of unblocking a tube or vent is unlikely to entirely remove any frozen water or air from the system. It will simply move it to a less awkward place.

Wear protective clothing. When the blockage clears there may be a sudden exhaust of cold gas or liquid cryogen and a risk of cold burns to exposed skin.

Figure 13 Check for nitrogen vessel blockages regularly and often and clear them as soon as possible

3.10. Warming up a system

Take care when you warm a system to room temperature; read the Operator's handbook and follow the instructions carefully.

All the chambers in the cryostat must be free to vent safely, even if you think that they are empty. If the system has been cold for a very long time, or there is a leak into the cryostat, air may have been cryopumped on to the cold surfaces inside the system. There is no way to tell whether this has happened. As the air evaporates its volume may increase very quickly and the vessel may not be strong enough to take the resulting high pressure.

Remember:

- 1 litre of liquid helium expands to 750 litres of gas at room temperature and atmospheric pressure (NTP), or becomes 1 litre of gas at 750 bar if it is not free to expand.
- 1 litre of gas at 4.2 K expands to 70 litres NTP, or becomes 1 litre of gas at 70 bar if it is not free to expand.

- Even if all of the liquid and gas has been removed, it is possible that some air is frozen in the vessel or the pumping line, and this will expand in a similar way.
- Until you warm up the system, you cannot tell whether there is any frozen air in one of the chambers. For your own safety, assume that it is there.

3.11. Dangerous cryogens

You need additional training before handling cryogens other than helium and nitrogen.

The correct handling procedures for the less common cryogens which may be toxic, flammable or explosive are not included in this booklet. If you are using cryogens other than liquid nitrogen or liquid helium it is important that you obtain the necessary training.

3.12. First aid treatment for cold burns

Flush the affected areas of skin with copious quantities of tepid water but do not use any form of direct heat such as hot water or a room heater. Move the casualty to a warm place (about 22 °C). If medical attention is not immediately available arrange for the casualty to be transferred to hospital without delay. While waiting for transport:

- Loosen any restrictive clothing.
- Continue to flush the affected areas of skin with copious quantities of tepid water.
- Remove any metallic straps, bracelets etc. from the affected area of skin.
- Protect frozen parts with bulky, dry, sterile dressings. Do not apply so tightly as to cause restriction of blood circulation.
- Keep the patient warm and at rest.
- Ensure ambulance crew or hospital is advised of details of the accident and first aid treatment already administered.
- Smoking and alcoholic beverages reduce the blood supply to the affected part and should be avoided.

Remember that there is a risk of creating a second injury if you put a frozen finger into your mouth to warm it up. The delicate tissues inside your mouth could be frozen too!

If the patient's lungs have been exposed to enough cold gas to cause distress, or if in doubt, take him or her to hospital immediately. Even transient exposure to cold gas can produce discomfort in breathing and can provoke an attack of asthma in susceptible people. If the victim is suffering from dizziness or loss of consciousness due to asphyxiation:

- Make sure that you are safe first (and in some cases this means that you should not enter the area without breathing apparatus)
- Summon medical help immediately
- Move the victim to a well-ventilated area if it is safe to do so
- Apply artificial ventilation or resuscitation if necessary.

4. Superconducting magnet systems

Many cryogenic systems include superconducting magnets which operate at very high fields. Extensive studies continue into the direct effects of magnetic fields on health[5] (especially in relation to clinical MRI, where patients are necessarily exposed to very high fields for diagnostic imaging) and the current recommendations are summarised in sections 4.4 and 4.5.
Far more hazardous are the indirect effects on stray ferromagnetic objects (including everyday items such as hand tools, keys and coins) and instrumentation and the results of a magnet quench (section 4.6).

Consider the following hazards (at least):

- Magnetic items may move suddenly and uncontrollably towards a magnet; an example graph showing the sudden increase of force at a particular distance is given in Figure 14. Most tools are magnetic.
- Someone could be trapped between a large magnetic item (such as a gas cylinder) and a cryostat, resulting in severe injury or death
- Medical electronic implants (such as pacemakers) may be affected by a magnetic field
- The magnetic field is three dimensional so the field may affect rooms on the floors above and below your laboratory, as well as on the same floor (Figure 15). Use the stray field map supplied with your system and determine whether steel reinforcement in floors and walls could be magnetised.
- Magnets may suddenly quench and release their stored energy into the liquid helium (see section 4.6)
- Remember all the potential cryogenic hazards summarised in section 3
- Magnetic data on credit cards, disks and other magnetic storage media may be corrupted.

Every magnet site should be reviewed individually to determine precautions to be taken against these hazards and it is strongly recommended that a formal site survey be carried out[6].

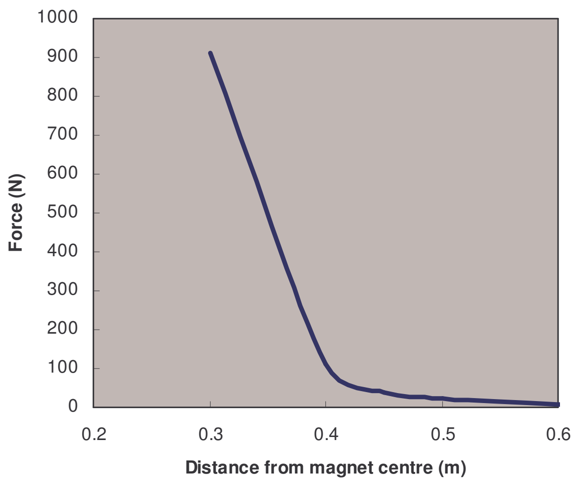


Figure 14 Example showing the force experienced by a 200 gram mild steel object as it approaches a large superconducting solenoid

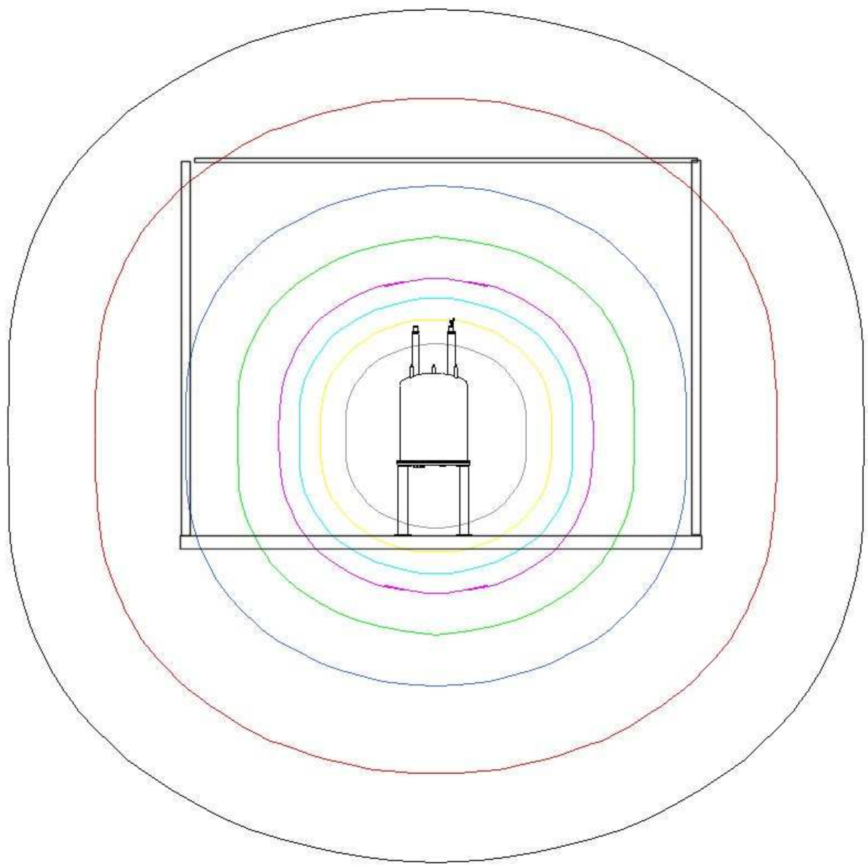
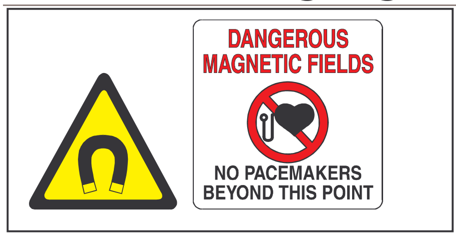


Figure 15 The field is three dimensional and affects areas on floors above and below your laboratory.

4.1. Before energising the magnet



Before you start to energise a magnet:

- Ensure that all loose ferromagnetic objects are secured or moved to a safe distance. These will normally be safe outside the 5 gauss field contour (see your stray field map).
- Check that the protection circuit is connected. Oxford Instruments magnets fitted with persistent switches are impossible to energise unless this condition is satisfied. Protection circuits are discussed further in section 5.4.
- Connect one ground wire between the earth points on the cryostat and the power supply and a second wire between the same cryostat earth and a laboratory earth point; refer to your installation manual for details. Note additional information in section 5.4.
- Check that there is an insulating rubber cover fitted over the current lead terminals.
- Display warning signs (preferably illuminated) at all the laboratory doors, to remind people that the magnet is operating.
- Display warning signs giving notice of the possible presence of magnetic fields and of the potential hazards in all areas where the field may exceed 5 gauss.

- Ensure that all electronics and interfacing equipment are removed to areas where the field level is sufficiently low; some guidelines are provided in Table 2 but you may need to refer to individual instruction manuals.
- Assess the safe working field level of all other equipment and take appropriate action.
- Check that the helium reservoir is protected by suitable pressure relief valves in case the magnet quenches.
- Consider carefully whether the exhaust gas or gas released by a pressure relief valve in the event of a quench could injure someone working on the system. If necessary, put guards around the hazardous regions.
- Check that there is enough liquid helium in the system.
- On systems with optical access the windows can be especially vulnerable. Unused windows should be protected by a metal cover; these will be supplied with the system. You are advised to guard "active" windows to provide a second line of defence against stray ferromagnetic objects.

4.2. While the magnet is at field

While the magnet is at field make the following checks regularly:

- Check the liquid helium and liquid nitrogen levels and refill if necessary.
- Check that the boiloff rates of helium and nitrogen gas are normal.
- Check that the warning signs are still in place: restrict access to unauthorised personnel.
- Do not bring magnetic objects close to the magnet. They should normally remain outside the 5 gauss limit. **Never attempt to check for the presence of a magnetic field with a ferromagnetic object such as a standard tool. You are risking serious injury or damage to equipment or personnel (see Figure 14).**
- Only use non-magnetic storage/transport dewars and non-magnetic trolleys for liquid helium and liquid nitrogen.
- Use non-magnetic tools to work on a system if the magnet is energised.
- Remember that even non-magnetic electrically conductive materials may experience a force or resistance to motion due to field induced eddy currents.
- Give a verbal warning to people entering the room; remember that keys and coins are often magnetic.
- Ensure that there is sufficient ventilation.

4.3. Effects on personnel and instrumentation

Other equipment may be directly affected by the presence of large magnetic fields. The field may cause permanent damage or it may only have a temporary effect until the field is removed. Use a stray field map of your system and Table 2 to provide guidance. If your magnet is Actively Shielded™ there will be two stray field maps provided; normal operation (shield is active) and one showing the maximum stray field burst during a quench, in which the field contours are much extended.

Personnel must be restricted so as to prevent access to areas with fields greater than 5 gauss; warning signs should be erected.
Use the information in "Maximum stray field burst during quench" in cases where two stray field maps are provided.

Safe working field	Equipment or restriction
1 gauss	Image intensifiers Electron microscopes Accurate measuring scales Graphics terminals Nuclear cameras
5 gauss	Pacemakers Public access without warning signs Cathode ray tubes
10 gauss	Computers Watches and clocks Credit cards
20 gauss	Magnetic storage media
50 gauss	Magnet power supply Shim coil power supply

Table 2 Guidelines for safe location of some sensitive equipment.

4.4. Threshold limit values (TLV) for exposure to magnetic fields

Guidelines on exposure to both static (DC) and time-varying (AC) magnetic fields are constantly evolving as new scientific and medical evidence is presented. It is therefore wise to refer to official legislation standards for a list of relevant documentation.

Table 3 summarises static field recommendations from three sources together with limits recently issued by the Council of the European Union. These limits relate to occupational exposure by personnel who work with magnetic fields; they do not apply to the general public.

Regulatory body	region	Time weighted average			Peak value		
		Whole Body	Limbs	Medical electronic device wearers	Whole Body	Limbs	Medical electronic device wearers
International Commission on Non-Ionizing Radiation Protection (ICNIRP)[7]	Europe	200 milliTesla (over 8 hours)	200 milliTesla (over 8 hours)	No value available	2 Tesla	5 Tesla	0.5 milliTesla
National Radiological Protection Board (NRPB)[8]	U.K.	200 milliTesla (over 24 hours)	200 milliTesla (over 24 hours)	No value available	2 Tesla	5 Tesla	0.5 milliTesla
American Conference of Governmental Industrial Hygienists (ACGIH)[9]	U.S.A.	60 milliTesla (over 8 hours)	600 milliTesla (over 8 hours)	No value available	2 Tesla	5 Tesla	0.5 milliTesla
Council of the European Union[10] – active since April 2004	Europe	200 milliTesla (over 8 hours)	No value available	No value available	No value available	No value available	No value available

Table 3 TLVs for DC magnetic fields (0 - 1 Hz)

In the context of magnets supplied by Oxford Instruments NanoScience, AC magnetic fields of low frequency will be experienced if

- An operator is located within the stray field region when the magnet is being ramped up or down.
- The operator moves into or out of the magnetic field.

TLV information for these cases is summarised in Table 4. The ICNIRP limits are closer to those being considered by the Council of the European Union. As before these limits relate to occupational exposure by personnel who work with magnetic fields; they do not apply to the general public.

		ICNIRP (Europe)[11]	NRPB (UK)[8]	ACGIH (USA)[9]
Activity in static field region	Frequency (Hz)	B (milliTesla)	B (milliTesla)	B (milliTesla)
Slow head turning	1	200	80	60
Rapid head turning	2	50	40	30
	3	22	27	20
	4	13	20	15
	5	8	16	12
	6	6	13	10
Brisk walk in or out	7	4	11	9
Running in or out	8	3	10	8

Table 4 TLVs for AC magnetic fields (1 – 8 Hz)

4.5. Medical implants

The operation of medical electronic implants, such as cardiac pacemakers, may be affected by static or changing magnetic fields.

Erect suitable notices to warn visitors and make sure that none of your staff is vulnerable.

Pacemakers do not all respond in the same way or at the same field level. You may not know that one of your visitors has a pacemaker so it is important to erect suitable signs to warn them of the danger. The stray fields caused by your magnet in other surrounding rooms may be enough to affect them.

Other medical implants, such as aneurysm clips, surgical clips or prostheses, may contain ferromagnetic materials. Therefore they may experience strong forces near the magnet which could result in injury or death. Rapidly changing fields (for example pulsed gradient fields) may induce eddy currents in any metallic implant, even if it is not magnetic, and generate heat.

4.6. Superconducting magnet quenches

There is always the risk of a quench, even in a very reliable and stable magnet. External factors can affect the stability of the magnet so you should always be prepared. There are three effects that must be considered; the collapse of the field, the possible generation of high voltages and the sudden release of cryogens as gas.

In the event of a magnet quench (either spontaneous or induced) the magnetic field will rapidly fall to zero. This may affect objects present in the room.

If you are using an Oxford Instruments NanoScience power supply for your magnet the output current will automatically be switched off safely.

Some large magnet systems are fitted with an Emergency Run Down Unit (ERDU); further details are provided in a dedicated ERDU document.

Ensure that you understand how and in what circumstances you should activate the ERDU.

Pressing the emergency run down button will make the magnet quench. There is always the risk that the quench will damage the magnet. Only use it if the magnetic field poses a serious threat to personnel, for example if someone has been trapped by a magnetic object.

In the event of a magnet quench all the cryogens may be released. The volumes of gases at room temperature will be approximately 70 m^3 for every 100 litres of cryogen (helium and nitrogen). Take precautions against asphyxiation as described in section 3.6.

If a superconducting magnet quenches releasing helium gas to the atmosphere you should evacuate the laboratory immediately and allow good ventilation until the helium gas has been dispersed. If you do not do this you may be asphyxiated.

There is always a risk of the magnet quenching. The stored energy in the magnet then evaporates most of the liquid helium very quickly. The helium recovery system is unlikely to be able to handle such a large amount of gas (perhaps 20 m^3 or more in a few seconds), and the relief valves will release the excess gas into the laboratory, displacing the air. If reasonably practicable, the cold gas should be vented in a safe area where nobody could be injured.

Use your system data to calculate the worst case oxygen depletion for the room containing the system as illustrated in section 3.6.

Actions following a magnet quench:

- In poorly ventilated areas evacuate the room immediately and do not enter the room again until you know that there is sufficient oxygen in the air.
- Check that pressure relief valves have re-sealed properly so that they do not let air back into the system.
- Replace any broken bursting disks (if your system has any).
- Check that the nitrogen vent ports are still clear (if your system has any) as described in sections 3.7 and 3.8.
- Refill the helium vessel as described in the chapter *Cryogen refill*.
- Carry out a standard 4.2 K electrical and continuity breakdown check.
- Re-energise the magnet according to instructions given in your Operator's handbook.

5. Working with electrical equipment

The following recommendations apply to electrical equipment supplied by Oxford Instruments NanoScience for use with laboratory systems including:

- Superconducting magnet power supplies
- Shim power supplies
- Temperature controllers
- Liquid cryogen level meters.

Each will be supplied with an individual instruction and service manual. This will contain Caution and Warning statements that you must read, particularly if repair or adjustment is required.

5.1. Protective ground

Unless it is being powered from its own internal batteries, the instrument must always be connected to an electrical ground (earth) when it is being used, to reduce the risk of electric shocks. The ground wire (green/yellow) in the instrument power cable must be connected to the laboratory electrical ground. Only use extension cables if they have an earth conductor. Do not disconnect the protective ground inside or outside of the instrument and do not have external circuits connected to the instrument when its protective ground is disconnected. It may be appropriate to use a residual current trip device as additional protection.

The instrument will not stop working if the earth wire is not connected, and there is no indication that you might be in danger. Make sure that it is checked regularly (at least annually) by a competent person.

5.2. Working environment

Do not use electrical equipment in:

- Rain or excessive moisture
- Flammable or explosive gases.

Unless specifically stated, Oxford Instruments' equipment is not designed to be water or splash proof, or to be used in areas where there are flammable or explosive gases or fumes.

5.3. Repair and adjustment

Some internal adjustments can be made to electrical equipment supplied by Oxford Instruments. Although we do not encourage you to make these adjustments we try to supply you with enough information to allow you to do it safely.

Lethal voltages are accessible inside the instrument. Disconnect the AC power supply before you remove the covers or fuses. IT IS NOT SUFFICIENT to switch off the main power switch. Only do this type of work if you are suitably qualified, are sufficiently skilled to understand all the risks you are taking and follow any local regulations that may apply.

There may be capacitors inside the instrument and power supply filter which are still charged to a high voltage even after the AC power has been removed. Discharge all of them carefully before you start work.

Some fault finding and calibration operations can only be carried out with the power connected to the instrument. If you have to reconnect the AC Power supply with the protective covers removed you must remember that you are putting your life at risk.

5.4. Electrical hazards from superconducting magnets

Superconducting magnets usually have high inductance and operate at high currents. A large amount of energy is therefore stored in the magnet when it is at field.

$$Stored\ energy = \frac{1}{2} L I^2$$

where L is the inductance of the magnet and I is the current in the magnet.

If a magnet quenches a voltage is induced of magnitude

$$Induced\,voltage = -L \frac{dI}{dt}$$

Since it is not uncommon for the current to decay at 100 As^{-1} it is possible to generate voltages of a few kilovolts between the current terminals on the top of the cryostat.

The protection circuit is designed to protect the magnet and the users from these hazards.

In addition, Oxford Instruments Superconducting magnet power supplies are designed to prevent high voltages in the event of a failure in the protection circuit.

Cryomagnetic systems may be fitted with “fixed” or “demountable” current leads.

Systems with fixed leads should remain connected to the (earthed) power supply at all times. You should also connect a high-current ground wire (earth cable) from the power supply earth terminal to the earth point on the cryostat. A tapped hole and bolt may be provided (often under the cryostat base plate), identified by the international earthing symbol as shown.

Some cryomagnetic systems are supplied with demountable current leads. These may be removed from the cryostat after the magnet is energised and put into persistent mode. The magnet power supply may then be disconnected. It is essential that a special “shorting plug” and “baffle stick” are then fitted in place of the demountable lead and your Installation Manual or Operator’s Handbook will explain how to do this. The shorting plug

- Helps protect the magnet.
- Keeps the cold electrical connectors free from ice.

In order to ground the system when the power supply is disconnected you must connect a high-current earthing cable from a suitable laboratory earth terminal to the earth point on the cryostat, identified as above. Refer to your installation manual for details.

For systems with demountable leads you should always make a record of the operating current and polarity and keep this with the system for reference.

Summary of electrical hazards from the magnet:

- Do not run the magnet without the protection circuit connected.
- Do not modify the protection circuit.
- Ground all equipment, including the cryostat and electronics.
- If the magnet is at field and has fixed leads then do not disconnect the magnet power supply.
- Fit the insulating rubber cover over the magnet current lead terminals.
- If the leads are demountable follow instructions in you operator's handbook that describe their removal and subsequent fitting of the shorting plug and baffle stick.

6. Lifting and transporting heavy equipment

Some cryogenic systems are so heavy that they can only be lifted by a large capacity crane, but nevertheless may contain very delicate components. If you choose the right way to lift the system you will be able to:

- Ensure your own safety
- Avoid damaging fragile equipment.

You must determine local laws and regulations relating to lifting and follow them.

Anyone lifting heavy equipment should be properly trained; these notes are not a substitute for proper training.

Use only the lifting points provided on the system.

Systems should be lifted only using the lifting points provided. You must never lift by putting a chain or lifting strap underneath the system as special skills are required to do this safely.

Use only lifting equipment that has been formally certified as safe, according to your local regulations.

All service engineers from Oxford Instruments NanoScience will require evidence of certification before any lifting equipment is used.

6.1. Lifting points

All Oxford Instruments equipment that is too heavy to lift by hand will be fitted with suitable lifting points which are designed to carry the weight of the system safely. They will be positioned so that the system will stay vertical when it is lifted. The safest way to lift systems is to use all the lifting points provided.

Figure 16 (left) shows lifting "lugs" that are welded directly to the outer vessel of the system. There will be four lugs and all should be used.

Figure 16 (right) shows one (of two) "collar" eyebolts screwed into a system top plate. Smaller systems or sub-systems may have a single eyebolt located vertically above the centre of gravity.

Figure 16 Lifting lugs and eyebolts as fitted to Oxford Instruments systems

Pairs of collar eyebolts must be oriented correctly (Figure 17).

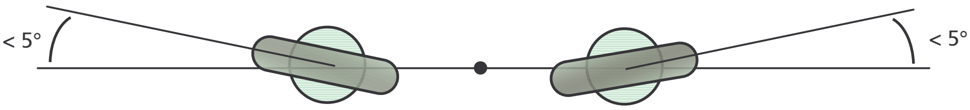


Figure 17 The plane of the eyes of a pair of collar eyebolts should be within ±5° of the plane containing the centre of gravity and the axes of the eyebolts

Collar eyebolts have a rated SWL for axial lifting, which also applies if the angle α in Figure 18 is less than 30°. If the angle is greater than 30° the SWL must be reduced by the appropriate factor (for details see BS4278:1984 or local equivalent).

You should always check in the Operator's Handbook in case your system has special lifting requirements.

6.2. Lifting equipment with an overhead crane

Before you use the crane:

- Check that the safe working load (SWL) of the crane will not be exceeded.
- Check that all lifting equipment has been tested, that it is properly certified and that you do not exceed its SWL.
- Always use closed shackles rather than open hooks.
- Confirm that the magnet (if any) is at zero field and the system is empty of cryogens.

When you are using a crane:

- Make sure that no one is allowed underneath an unsupported load.
- Always stand clear of the load in case the crane or lifting straps fail.
- Lift the system slightly clear of the ground and check it for balance and stability before lifting it higher; don't allow the load to swing.
- Avoid sudden movements which would impose a high shock load.
- Make sure that the lifting cable remains vertical so that the load cannot slide sideways as one side leaves the floor before the other.

Never work underneath an unsupported system hanging from a crane. If the system falls you may be killed.

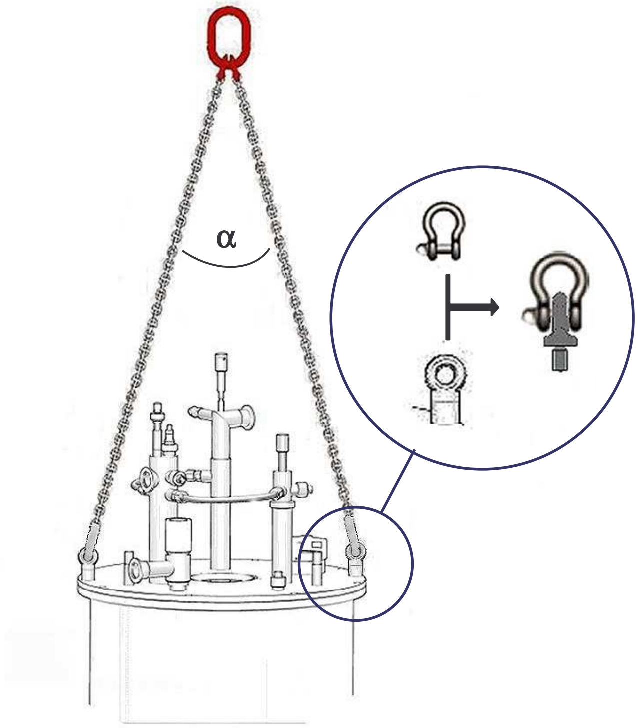


Figure 18 Lift your cryostat safely using appropriate and certified lifting equipment.

6.3. Transporting systems safely

Most systems can be transported safely on a pallet using a trolley or fork lift. However, remember that:

- Some tall systems have a high centre of gravity and can fall over easily
- Systems should be moved gently because they are fragile
- Systems should always remain vertical.

6.4. Maintenance

Have the eyebolts, lifting points and all other lifting equipment regularly inspected by a competent person, who will check that they are free from cracks, distortion, and any other defects.

7. Poisons and hazardous substances

Certain Oxford Instruments systems contain materials that are poisonous or hazardous in other ways. For instance, some window materials are poisonous. All may be handled safely if the recommended procedures are followed carefully.

Consider identifying a special working area and monitor it for contamination regularly.

Hazardous materials will be supplied with suitable documentation to warn you of potential hazards. The (British) Control of Substances Hazardous to Health (COSHH) regulations require that this information is easily available to anyone working with these materials and the COSHH form for a material is often the best way to give you this information.

Before disposing of this equipment, it is important to check with the appropriate local organisations to obtain advice on local rules and regulations about disposal and recycling.

You **must** contact Oxford Instruments NanoScience Customer Support (giving full product details) before any disposal begins.

7.1. Radioactive Sources – Cobalt-60

This safety information is specific to Cobalt-60 sources supplied by Oxford Instruments. If you are using any other source then additional precautions may have to be taken.

You must determine local laws and regulations relating to Cobalt-60 sources and follow them.

Radioactive cobalt-60 sources (^{60}Co) are sometimes used as thermometers on dilution refrigerator systems operating at temperatures below 100 mK. Sources supplied by Oxford Instruments NanoScience normally have an activity of less than 185 kBq. If a source is to be supplied to you then details of the source (isotope, activity, form, emitter type etc.) and specific safety information will be sent to you.

However some general safety precautions are repeated here:

- The Cobalt-60 crystals should only be handled by trained personnel.
- The crystal should always be kept in its lead container or transport packaging until it is required. If you have a local radiation store, store it there.
- Once removed from its packaging it must not be left unattended.
- Do not handle with your bare hands. Always use plastic non-powdered gloves and stainless steel tweezers. Work smartly with the source but do not rush unnecessarily.
- Avoid direct body contact with the crystal. If contact takes place wash hands and areas of contact with soap and water immediately.
- Do not drop or cut the crystal.
- Do not stare directly at the source as far as reasonably practicable as the eyes are particularly sensitive to ionising radiation. Keep the eye to crystal separation greater than 30 cm and do not focus directly on the crystal for any longer than is necessary to mount it.
- Do not use naked flames in the vicinity of the source.
- Wash your hands thoroughly with soap and water immediately after working with the source.

If you have a radioactive source, local regulations may require you to register it. In any case you should ensure that you comply with all local, national and international rules and regulations.

Appendix A Properties of helium and nitrogen

	Helium-4	Nitrogen
Chemical formula	^{4}He	N_2
Molecular weight	4	28
Normal boiling point (NBP) (K)	4.22	77.3
Critical point (K)	5.2	126.6
Liquid density at NBP ($g \cdot cm^{-3}$)	0.125	0.807
Ratio of gas at 273K (0°C),1 atm. : liquid at NBP	750	694
Latent heat of vaporisation at NBP ($J \cdot g^{-1}$)	20.9	198
Liquid at NBP boiled off by 1 watt (l/hour)	1.38	0.0225
Gas density relative to dry air at 288K (15°C) and 1 bar	0.14	0.98
Gas density at 273 K (0°C) and 0.101325 MPa	0.166	1.165
Fire/explosion hazard	No	No
Air liquefaction hazard	Yes	Yes
Asphyxiation hazard	Yes	Yes

Appendix B Risk Assessment

A "Risk Assessment" for an installed cryomagnetic system will consider and evaluate all the risks described in this booklet and implement mitigating procedures where necessary. You are responsible for the preparation of a Risk Assessment before any maintenance, inspection, modification or repair work is carried out; this is a formal requirement by engineers from Oxford Instruments NanoScience.

If you require advice or assistance in the preparation of a Risk Assessment please contact the Helpdesk at Oxford Instruments NanoScience[6].

References

[1] *Cryogenics Safety Manual*, The British Cryoengineering Society, 1998 (ISBN 0 8543 2605 7)

[2] Equipment described in this booklet is available from Oxford Instruments Direct at www.oxford-instrumentsdirect.com

[3] For site guidance and service work contact Oxford Instruments NanoScience Customer Support at helpdesk.nanoscience@oxinst.co.uk.

[4] F A D Alexander and H E Himwick, *American Journal of Physiology*, **126**, 418 (1939)

[5] Refer to www.MRIsafety.com for an in-depth discussion and extensive references.

[6] For site guidance and service work contact Oxford Instruments NanoScience Customer Support at helpdesk.nanoscience@oxinst.co.uk.

[7] Guidelines on Limits of Exposure to Static Magnetic Fields, *Health Physics* **66**,100-106 (1994), International Commission on Non-Ionizing Radiation Protection (ICNIRP)

[8] Board Statement on Restrictions on Human Exposure to Static and Time varying Electromagnetic Fields and Radiation, Volume 4, No. 5, 1993, National Radiological Protection Board, Chilton, Didcot, Oxon OX11 0RQ

[9] Documentation of the Threshold Limit Values for Physical Agents, ACGIH (American Conference of Governmental Industrial Hygienists) Worldwide, 1330 Kemper Meadow Drive, Cincinnati, OH 45240-1634, www.acgih.org

[10] Amended Proposal for a Directive of the European Parliament and of the Council on the minimum Health and Safety Requirements Regarding the Exposure of Workers to the Risks Arising from Physical Agents (Electromagnetic Fields), Council of the European Union, Interinstitutional File: 1992/0449/C (COD).

[11] Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields (up to 300 GHz), *Health Physics* **74**,494-522 (1998), International Commission on Non-Ionizing Radiation Protection (ICNIRP)