Magnetic Field Safety Guide

Environmental Health and Safety

1.0 Purpose and Requirements

This guide will present a summary of the basics of magnetic field safety, biological effects, and exposure limits to be used at Cornell University. Figures 1 and 2 list some typical magnetic field strengths that once can find in every day life. This may be useful when exposure limits are discussed.

Questions or comments concerning this guide may be sent to Jeff Leavey at JAL247@cornell.edu.

2.0 Scope

This guide applies to all users of devices and equipment designed to generate magnetic fields, both static and time varying. Examples include MRI (magnetic resonance imagining), SQUID (superconducting quantum interface device), particle accelerators, computer drive erasers, etc. Shielded equipment have greatly reduced field levels at normal distances from the shielding surface but may still exceed safety limits at close ranges.

In addition, large motorized equipment may generate spurious magnetic fields that may exceed safety limits.

A magnetic field survey can determine where or if equipment exceeds safety limits. Contact Environmental Health & Safety to request a survey.

3.0 Definitions

- B Field
  Magnetic flux density or magnetic induction. This quantity is considered the better measure of health hazards than the H field. The units are tesla (T) and gauss (G).
- H Field
  Magnetic field strength, measured in amps per meter (A/m).
- E Field
  Electric field strength, measured in volts per meter (V/m).

- μ_0
  Permeability of free space and is the ratio of B to H. For free space and (for practical purposes) for tissue, it has a value of $4\pi \times 10^{-7}$ weber/A-m.
- Tesla
  See B field. 1 T = 10,000 G = 1 weber/m^2.

3.1 Conversions

Some useful conversions between units are:

- 1 μT = 0.7958 A/m
- 1 A/m = 1.257 μT
- 1 T = 10,000 gauss

4.0 Biological Effects of Magnetic Fields

Effects are broken into two broad groups: physical effects where mechanical action occurs and biological effects that occur at the chemical and cellular level.

4.1 Physical Effects – Static Fields

By far the most important effect here is from the attraction of magnetic objects in or on the body by the magnetic field. Objects such as pacemakers, surgical clips and implants, clipboards, tools, jewelry, watches, mops, buckets, scissors, screws, etc. have all been documented as being potential hazards. Even low mass items can become hazardous when moving at high speed. Much of this experience has come from medical MRI systems. Magnetic objects will try to align themselves with the magnetic field lines. If an implanted object tries to do this, the torquing may cause serious injury.

In general, the quantity of ferritic or martensitic steel in an object will affect it's magnetic ability: the greater the quantity of these components, the greater the ferromagnetism. Austentitic steel is not magnetic. In addition, iron, nickel, and cobalt are magnetic and add to the items magnetic ability. All types of 400 series stainless steels are magnetic. Most, but not all, series 300 stainless steels are austentitic and not magnetic.

Modern pacemakers are designed to be tested or reprogrammed with the use of a small magnetic external to the body. Static fields can close reed switches and cause the pacemaker to enter test, reprogram, bypass, etc. modes with possible injury.

4.2 Physical Effects – Time Varying Fields

Effects of time varying fields are similar to those of static fields with a few major differences. First, an electric current can be induced when a conductor is in a time varying field. The human body is a conductor and so is moving blood. In such a field small currents not normally present in the body can be produced. Usually this is not a concern, but pacemaker users could be at reisk. The induced currents may cause the pacemaker to incorrectly start pacing or even prevent pacing when it is actually needed.

A general rule of thumb is 1 T/sec can induce about 1 $\mu A/cm^2$ in the body. Ambient current densities in the heart are about 10 mA/m^2 (1 $\mu A/cm^2$). At this level or less biological effects have not been demonstrated. At 100 to 1000 mA/m^2 changes in the threshold for nerve and muscle action occur, with a potential health hazard. However, the magnetic field necessary to generate 100 mA/m^2 is very large.

Induced currents can cause local heating, the major effect from time varying fields. Resistance heating in local areas of the body has caused burns in some medical MRI patients. The cause is the radiofrequency range time varying field. Low frequency fields usually do not contribute greatly to this effect. The ambient heat load of the body while resting is about 1 – 2 watt/kg. MRI examinations at about 0.15 – 2 T and millisec pulsing could add about 0.4 – 2 W/kg extra. While various parts of the body dissipate heat differently, it is this locally deposited extra heat that causes the burns.

4.3 Biological / Other Effects – Static Fields

The ability of static fields to cause cancer and other bio effects is greatly disputed. Much more work must be done in this area before a consensus opinion can be found. However, some conservative limits are proposed based on the best available data.

Based on data from MRI usage, static fields may cause a small, reversible effect on electrocardiogram data. The cause is the interaction of moving blood (a conductive medium) and the field in the heart. The effect was minimal below about 2 T (but was seen as low as 0.1 T) and is not considered a concern.

4.4 Biological / Other Effects – Time Varying Fields

The ability of static fields to cause cancer and other bio effects is greatly disputed. Much more work must be done in this area before a consensus opinion can be found. However, some conservative limits are proposed based on the best available data.

An interesting effect that has only been reported at very high fields (e.g. >4 T) is magnetophosphenes. Light flashes can be seen when the eye moves in a very strong field. It is thought that the induced current in the optic nerve causes this effect. Current densities of about 17 $\mu A/cm^2$ are associated with this. No magnetophosphenes have been reported at 1.95 T or less, but have been seen at 4 T on an experimental MRI system.

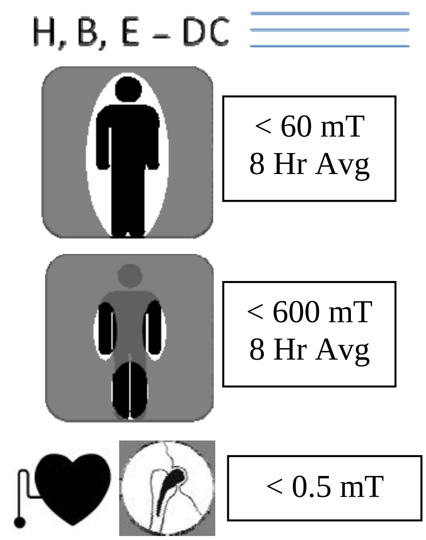
Specifically at 50/60 Hz, minor effects have been reported at 0.5 to 5 mT (5 to 50 gauss). At 5 to 50 mT (50 to 500 G) some visual and nervous system effects have been reported. At 50 to 500 mT (500 to 5000 G) stimulation of nerve and muscle tissue has been reported. Above 500 mT (5000 G) the induced currents can upset cardiac rhythm or cause ventricular fibrillation. All of these effects are from induced currents (IRPA, 1990).

Also at 50/60 Hz there has been no positive link proven between cancer or leukemia and magnetic fields. Some studies show a link and some show no link but all are based only on statistical analysis.

5.0 Magnetic Field Exposure Limits

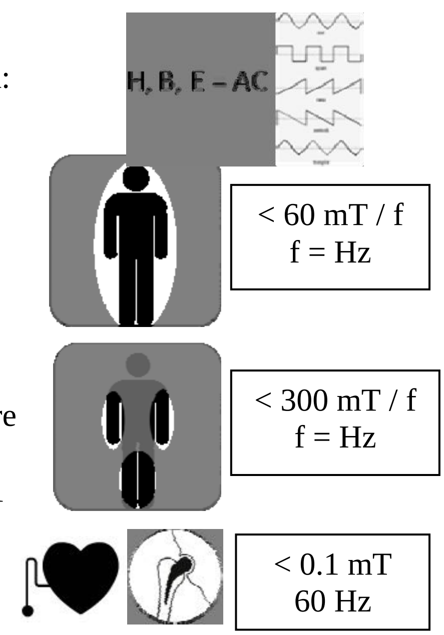
Because there are no regulatory limits and much biological data is unclear, the most conservative limits from recognized organizations will be used. Limits are primarily from the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLV) data. The International Radiation Protection Association (IRPA) published a guide in 1990 and is used here.

Limits will be updated by EH&S as new data is published.



5.1 Static Fields (ACGIH TLVs 2008)

- Routine occupational exposures should not exceed 60 mT (600 G) to the whole body on an 8 hr time weighted average.
- Routine occupational exposures should not exceed 600 mT (6000 G) to the extremities on an 8 hr time weighted average.
- A maximum ceiling (i.e. maximum value at any time) should be 2 T for the whole body and 5 T for the extremities.
- Pacemaker users or others with magnetic implants should not exceed 0.5 mT (5 gauss) at any time.



5.2 Time Varying Fields (ACGIH TLVs 2008)

- At 1 Hz to 300 Hz the ceiling exposure should not exceed:
  Whole body = 60 mT / f where f = frequency in Hz and
  Arms and legs = 300 mT / f and
  Hands and feet = 600 mT / f.
- From 300 Hz to 30 kHz the ceiling whole or partial body exposure should not exceed 0.2 mT.
- Fields at 1 Hz or less are considered static (see Section 5.1).
- For 50/60 Hz fields specifically, the occupational exposure for an 8 hr work day is 0.5 mT (5 gauss).
- For pacemaker users at 60 Hz specifically the limit is 0.1 mT (1 G).
- For fields over 30 kHz, contact EH&S.

5.3 Public Areas

- All public spaces are limited to less or equal to 5 G for static fields and less than or equal to 1 G for 50/60 Hz fields.

6.0 General Safety Consideration

6.1 Magnetic Objects

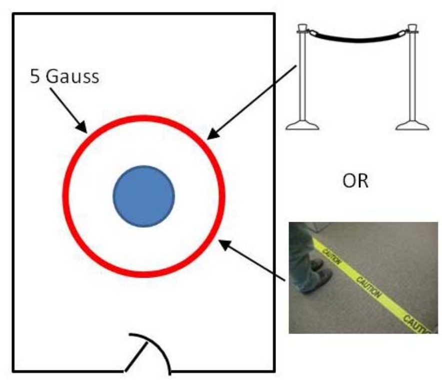
The obvious safety action is to prevent any magnetic material from entering the work area. Because the hazard from flying objects depends on many factors, users must be continuously watchful. Do not underestimate the rapid increase in field strength as one approaches the source; a gradual pull may not always be felt first.

Please be sure that your magnet will not generate a hazard area or affect equipment outside your work area. EH&S can help you survey the area if requested. Of particular concern are surrounding lab and office areas, especially if the magnet is unshielded.

6.2 Posting and Sign Requirements

A warning sign is required to be posted at the entrance to labs or spaces where magnetic fields exceed any of the limits listed above. An example sign is shown in Figure 3. A Powerpoint version of the sign is available from EH&S for custom editing.

In addition to the warning signs posted at the doorways, some method to indicate the 5 gauss line around the magnet is required. For example, a painted line or tape placed on the floor around the magnet where the field is 5 gauss could be used. Another example is a chain, rope, or fence indicating the 5 gauss line around the magnet. Whatever method is used, egress from the area in the event of an emergency shall not be blocked or prevented.



6.3 Cryogenic Safety

Superconducting magnets using liquid helium and/or nitrogen present an additional safety concern with the handling of cryogenic liquids. Safety glasses or goggles, cryogenic gloves and body protection are required when handling these substances.

With helium vapor, prolonged exposure can cause frostbite. EH&S offers a cryo safety class which is recommended if you will work with liquid He or N.

In some lab or space configuration, oxygen displacement is a serious concern. The gas to liquid volume ratio for helium is 700 to 1 and 695 to 1 for nitrogen. Exposure to pure inert gas environments for 5 to 10 seconds is sufficient to cause unconsciousness. Longer exposure will cause asphyxiation and death. Oxygen monitoring may be required; contact EH&S for assistance.

N_2	=	-196°C	-321°F
He_2	=	-269°C	-452°F

7.0 References

- Safety Consideration in MR Imaging, Radiology, Vol 176, pp. 593-606, 1990.
- Threshold Limit Values Handbook, ACGIH, 2008 Edition.
- Documentation of ACGIH TLVs, ACGIH, pg. 686, 1987.
- Annual Report of the Committee on Threshold Limit Values and Biological Indices, Appl Occup Env Hyg, Vol 6 No 9, pg. 800, 1991.
- Human Exposure to Static and Time-Varying Magnetic Fields, Health Physics, Vol 51 No 2, pp. 215-225, 1986.
- IRPA Interim Guidelines on Limits of Exposure to 50/60 Hz Electric and Magnetic Fields, Health Physics, Vol 58 No 1, pp. 113-122, 1990.
- Health Effects of Occupational Exposure to Steady Magnetic Fields, AIHA Journal, Vol 43 No 6, pp. 387-394, 1982.
- Guidelines on Limits of Exposure to Static Magnetic Fields, Intl Commission on Non-ionizing Radiation Protection (ICNIRP), Health Physics, Vol 96 No 4, pp. 504-514, 2009.

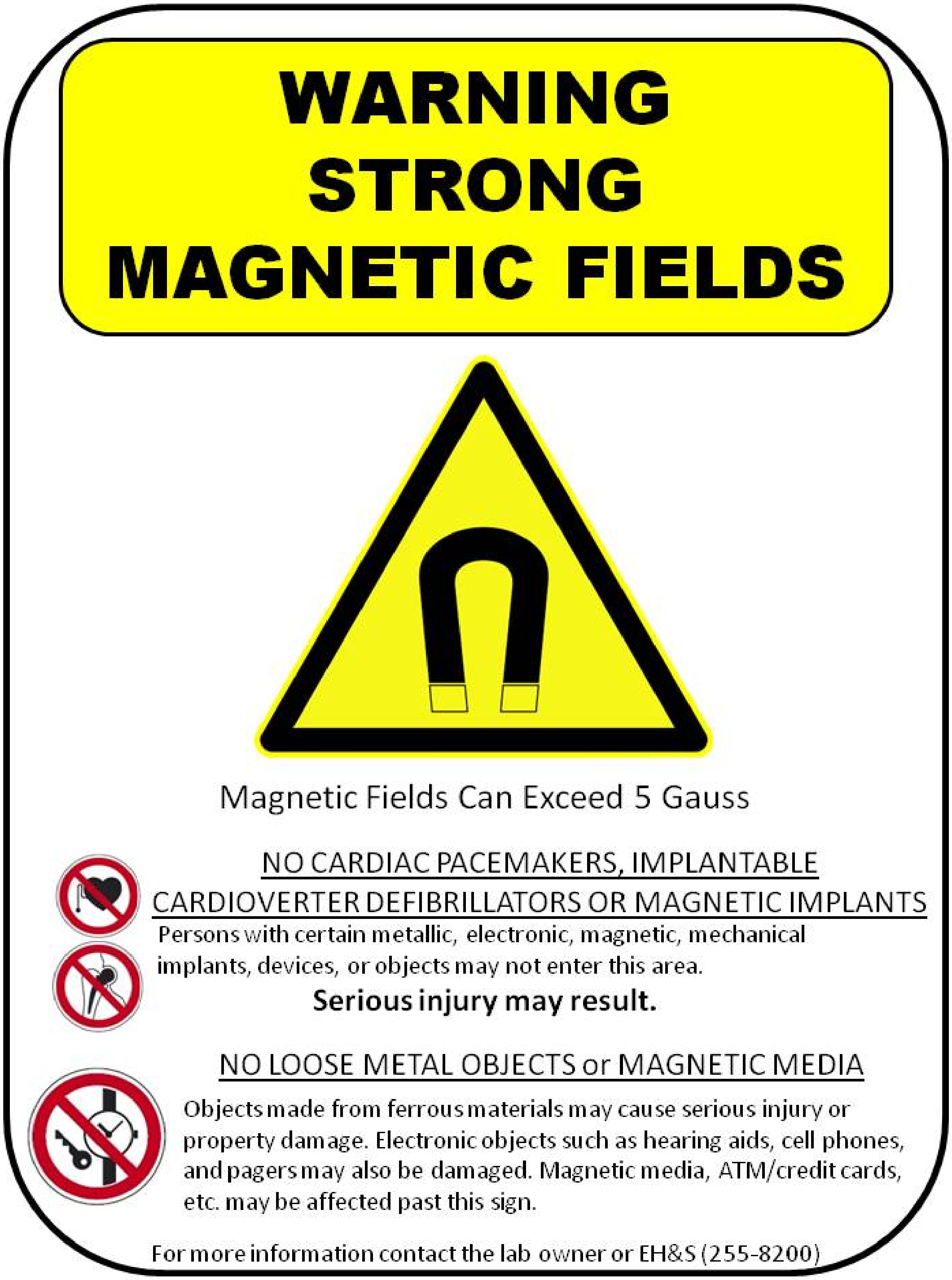
Figure 1

Appliance	Magnetic flux density (μT) at distance z		
	z = 3 cm	z = 30 cm	z = 1 m
Blenders	25 - 130	0.6 - 2	0.03 - 0.12
Can openers	1,000 - 2,000	3.5 - 30	0.07 - 1
Clothes dryers	0.3 - 8	0.08 - 0.3	0.02 - 0.06
Clothes washers	0.8 - 50	0.15 - 3	0.01 - 0.15
Coffee makers	1.8 - 25	0.08 - 0.15	0.01
Crock pots	1.5 - 8	0.08 - 0.15	0.01
Dishwashers	3.5 - 20	0.6 - 3	0.07 - 0.3
Drills	400 - 800	2 - 3.5	0.08 - 0.2
Electric ovens	1 - 50	0.15 - 0.5	0.01 - 0.04
Electric ranges (over 10 kW)	6 - 200	0.35 - 4	0.01 - 0.1
Electric shavers	15 - 1,500	0.08 - 9	0.01 - 0.3
Fans & blowers	2 - 30	0.03 - 4	0.01 - 0.35
Fluorescent desk lamps	40 - 400	0.5 - 2	0.02 - 0.25
Fluorescent fixtures	15 - 200	0.2 - 4	0.01 - 0.3
Garbage disposals	80 - 250	1 - 2	0.03 - 0.1
Hair dryers	6 - 2,000	0.01 - 7	0.01 - 0.3
Irons	8 - 30	0.12 - 0.3	0.01 - 0.025
Microwave ovens	75 - 200	4 - 8	0.25 - 0.6
Mixers	60 - 700	0.6 - 10	0.02 - 0.25
Portable heaters	10 - 180	0.15 - 5	0.01 - 0.25
Refrigerators	0.5 - 1.7	0.01 - 0.25	0.01
Sabre & circular saws	250 - 1,000	1 - 25	0.01 - 1
Television	2.5 - 50	0.04 - 2	0.01 - 0.15
Toasters	7 - 18	0.06 - 0.7	0.01
Vacuum cleaners	200 - 800	2 - 20	0.13 - 2

Figure 2

Exposure	Frequency	Magnetic flux	Remarks
Everyday life	DC 50/60 Hz 50/60 Hz	30 - 70 μT 0.1 - 0.8 μT 1 - 30 μT	Earth's field Household Near appliances
Power distribution	DC 50/60 Hz	10 - 25 μT 10 - 100 μT	
Transportation (Future)	DC	2 - 100 mT	Maglev
Medical	DC DC 1 - 75 Hz	0.15 - 1.5 T 0.1 T 1 - 30 mT	MRI (patient exposure) Prosthetic devices Bone healing (patient exposure)
Electrolysis	DC	10 - 50 mT	Operator exposure
High-energy technologies	DC	1 - 100 mT 0.6 - 1.5 T	A few minutes/day
Induction heating, welding, etc.	50/60 Hz 1 - 1000 kHz	1 - 130 mT 0.1 - 10 mT	Operator exposure
Communication	10 - 100 kHz	1 - 50 μT	
Personnel identification	6 - 1000 kHz	0.1 mT	

Figure 3



WARNING
STRONG
MAGNETIC FIELDS
Magnetic Fields Can Exceed 5 Gauss
NO CARDIAC PACEMAKERS, IMPLANTABLE
CARDIOVERTER DEFIBRILLATORS OR MAGNETIC IMPLANTS
Persons with certain metallic, electronic, magnetic, mechanical
implants, devices, or objects may not enter this area.
Serious injury may result.
NO LOOSE METAL OBJECTS or MAGNETIC MEDIA
Objects made from ferrous materials may cause serious injury or
property damage. Electronic objects such as hearing aids, cell phones,
and pagers may also be damaged. Magnetic media, ATM/credit cards,
etc. may be affected past this sign.
For more information contact the lab owner or EH&S (255-8200)

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Care with Cryogenics

Care with **Cryogenics**

This document is designed to be used in conjunction with BOC's publications: "Controlling the Risks of Oxygen" or "Controlling Risks of Inert Gases" and is an overview of the hazards and precautions to be taken when handling low temperature liquefied gases. People with a special responsibility for safety or who are engaged in teaching or training others in the use of low temperature liquefied gases should refer to more comprehensive materials available from EIGA at www.eiga.org.

Index

Introduction

There are a number of potential hazards when using gases that are liquefied by cooling them to low temperatures. These may be referred to as "CRYOGENIC" liquids. The gases covered in this document and their physical properties are detailed in the table below. All the gases are non-flammable, although liquid oxygen is an oxidant and can promote vigorous combustion of many materials.

Property	Oxygen (O2)	Nitrogen (N2)	Argon (Ar)	Helium (He)	Carbon dioxide (CO2)
Molecular weight	32	28	40	4	44
Colour of gas	None	None	None	None	None
Colour of liquid	Light Blue	None	None	None	None
Normal boiling point (tb) at Patm (°C)	-183	-196	-186	-269	-78.5 (sublimes)
Ratio of volume gas (measured at 15°C and Patm) to volume of liquid, (measured at Tb and Patm)	842	682	822	738	845 (solid)
Relative density of gas at Patm (Air = 1)	1.105@25°C	0.967@25°C	1.380@0°C	0.138@0°C	1.48@25°C
Liquid density at Tb and Patm (kg/m3)	1142	808	1394	125	1564 (solid)
Latent heat of evaporation at Tb (kj/kg)	213	199	163	21	573 (sublimation)

Low temperature hazards

Cold burns, frostbite and hypothermia

Cold burns and frostbite

Because of the low temperature of liquefied atmospheric gases, the liquid, cold vapour or gas can produce damage to the skin similar to heat burns. Unprotected parts of the skin coming into contact with uninsulated items of cold equipment may also become stuck to them and the flesh may be torn on removal.

Cold vapours or gases from liquefied atmospheric gases may cause frostbite, given prolonged or severe exposure of unprotected parts. A symptom that usually gives warning of freezing is local pain, however sometimes no pain is felt or it is short lived. Frozen tissues are painless and appear waxy, with a pale yellowish colour. Thawing of the frozen tissue can cause intense pain. Shock may also occur.

Treatment of cold burns

The immediate treatment is to loosen any clothing that may restrict blood circulation and seek hospital attention for all but the most superficial injuries. Do not try to remove clothing that is frozen to skin. Do not apply direct heat to the affected parts, but if possible place in lukewarm water. Clean plastic kitchen film or sterile dry dressings should be used to protect damaged tissues from infection or further injury, but they should not be allowed to restrict the blood circulation. Alcohol and cigarettes should not be given.

Where exposed skin is stuck to cold surfaces such as uninsulated cryogenic pipework, isolate the source of the cold liquid and thaw with copious amounts of tepid water until the skin is released.

Effect of cold on lungs

Transient exposure to very cold gas produces discomfort in breathing and can provoke an asthma attack in susceptible people.

Hypothermia

Low air temperatures arising from the proximity of liquefied atmospheric gases can cause hypothermia and all people at risk should wear warm clothing.

Typical symptoms of hypothermia are:

i. A slowing down of physical and mental responses.
ii. Unreasonable behaviour or irritability.
iii. Speech or vision difficulty.
iv. Cramp and shivers.

Treatment of hypothermia

People appearing to be suffering from hypothermia should be wrapped in blankets and moved to a warm place. Seek immediate medical attention. No direct form of heating should be applied except under medical supervision.

Causes and avoidance of exposure

Contact with cold surfaces

Where possible, insulate all exposed cold surfaces using suitably approved materials.

Splashes and spillages

- Use suitable PPE.
- Use approved manual handling equipment when moving vessels containing cryogenic liquids.
- Report all leaks immediately.

Prolonged exposure to low temperature environments

- Use suitable insulating PPE.
- Minimise time of exposure.

Inadequate design/incorrect choice of materials

- Only use competent system designers.
- Only use approved materials.
- Conduct regular planned preventative maintenance.
- Do not exceed the flow rate specified for the equipment.

Overpressurisation

When vaporised into gas, all of these liquefied gases increase many hundreds of times in volume. This results in a large pressure increase if the volume change is restricted. The normal inleak of heat through the insulated walls of the storage vessels and pipework into the cryogenic liquid raises its temperature and hence, with time, the pressure rises due to the generation of gas.

Cryogenic systems must therefore be designed with adequate pressure relief on storage vessels and anywhere where liquid may be trapped, such as pipework between valves.

If liquid is vented into the atmosphere, it vaporisers with a consequential large expansion in volume which can be very noisy. Therefore, venting should be controlled and adequate precautions taken to protect personnel. The cloud of cold gas vented into atmosphere can also present a risk.

Embrittlement

The most significant consideration when selecting equipment and materials for low temperature use is that of possible brittle fracture. Carbon steel is extremely brittle at the cryogenic temperatures of liquid nitrogen, argon and oxygen. (Certain types of carbon steel can be used with cryogenic carbon dioxide because it is relatively warm in comparison to liquid nitrogen, argon and oxygen.) Metals used in any equipment should satisfy the impact test requirements of the design code being used.

If there is a change in the use of a plant from its original design, it may result in the liquid usage rate exceeding the capacity of the vaporising equipment. This can cause cryogenic liquid to reach parts of the equipment that were not originally intended for low temperature conditions, increasing the risk of potential brittle fracture.

Liquid air condensation

Whilst nitrogen and helium appear to be safe from the risk of combustion because they are inert, these liquids are cold enough at normal boiling points to condense air from the atmosphere. This condensed air contains higher oxygen content than normal air, increasing the risk of combustion. It is therefore essential that the vessel is properly insulated. It is also recommended to exclude combustible insulating materials from liquid nitrogen and helium systems and installations. Liquid argon cannot condense air from the atmosphere.

Dense cold vapour

Due to the relatively high density of the cold vapour of the liquids, the gases may collect and persist in areas which may not be immediately recognisable as confined spaces, posing an oxygen deficiency or enrichment hazard. Manholes, trenches, basements, drainage systems, underground service ducts and any low lying, poorly ventilated areas may pose such a hazard and entry into these areas should be controlled by a Permit to Work.

Preventative measures

Information and training

All people who work with low temperature liquefied gases or systems using such gases should be given adequate training on the risks of asphyxiation, fire hazards, cold burns, frostbite and hypothermia. Special attention should be drawn to the insidious nature of the risks due to the rapidity of the effects, coupled with the fact that an operator may be completely unaware that a hazardous condition has developed.

Protective clothing

Protective clothing is only intended to protect the wearer handling cold equipment from accidental contact with liquefied atmospheric gases or parts in contact with it. Non-absorbent leather gloves should always be worn when handling anything that is, or has been recently, in contact with cryogenic liquids. The gloves should be a loose fit so that they can easily be removed if liquid should splash onto or into them. Gauntlet gloves are not recommended because liquid can easily splash into the wide cuff.

It is essential that clothing is kept free of oil and grease where oxygen is in use.

If clothing becomes contaminated with liquefied atmospheric gases or their vapour, the wearer should ventilate it for a minimum of five minutes whilst walking around in a well-ventilated area. The risk with contamination by liquid oxygen is of rapid burning of the material, even when started via a tiny ignition source (a spark or a piece of burning tobacco). Therefore, in these circumstances it is essential to ventilate clothing for at least 15 minutes (or replace it) and to keep away from any such source of ignition.

Woven materials are best avoided, but if they are used for protective clothing, it is essential to ensure that they do not become saturated with cold liquid.

Goggles or a facemask should be used to protect the eyes and face when carrying out operations where spraying or splashing of liquid may occur. Overalls or similar clothing should be worn. These should be without open pockets or turn-ups where liquid could collect. Trousers should be worn outside boots for the same reason.

A person whose clothing catches fire should be deluged with water from a shower, hose or series of fire buckets and moved into the fresh air as soon as possible. It is very dangerous to attempt to rescue a person catching fire in an oxygen-enriched atmosphere, as the rescuer is likely to catch fire as well. (In some cases it may be possible to enter such a space if the rescuer is totally deluged with water and protected by constant water hosing).

Warning signs

Wherever cryogenic gases are used or stored, hazard warning signs should be displayed as necessary and barriers placed indicating the extent of the hazard. Any pictogram used should comply with the Health and Safety (Safety Signs and Signals) Regulations 1996 and BS5378.

Liquid helium

Because of its low boiling point and latent heat of evaporation, liquid helium is supplied in specifically designed dewars which must be handled with care at all times. In particular, liquid helium dewars should not be filled with other liquids whose higher specific gravity might result in failure of the suspension system.

This liquid can only be transferred in vacuum insulated lines and equipment. Even some types of steels which are satisfactory at liquid nitrogen temperature, become brittle when in contact with liquid helium.

Any receiving equipment or dewars which have been pre-cooled with liquid nitrogen must be clearly identified and subsequently purged with pure helium gas prior to transfer to liquid helium service. Liquid helium can solidify all other known gases and liquids.

The oxygen enrichment hazard, due to condensation of the air is much more significant than with liquid nitrogen. All equipment which may be at liquid helium temperatures must be kept clean to the same standards as liquid oxygen installations.

Dewars

Safe working procedures must be developed and adhered to for the use of dewars, including their transportation within and around the premises. Special safety procedures are necessary when carrying filled dewars in lifts. Only use dewars that are correctly and clearly labelled. Always ensure that adequate ventilation is provided in areas where dewars are filled, used or stored.

Adequate emergency procedures must be in place in the event of a liquid spillage, cold burn or suspected asphyxiation.

Ice plugs can form in the neck of dewars and can be ejected at high velocity due to pressure build up. Avoid them by ensuring that protective caps are always used and that dewars are fully emptied before being taken out of use or put into storage.

Refer to BCGA (British Compressed Gases Association) CP30 for further guidance.

Further Information

For further information please refer to the following BOC publications:

Siting of liquid cylinders or vessels in buildings (CRY/004521)
Movement of cryogenic vessels in lifts (CRY/007614)
Transport by vehicle of liquid nitrogen (CRY/004545)

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