SCHOOL OF BASIC SCIENCES
OCCUPATIONAL SAFETY AND HEALTH SERVICE

ÉCOLE POLYTECHNIQUE
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Series « What should I know? »

Cryogenics safety leaflet

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Physical properties of cryogens

Very low temperature

The hazards related to cryogenic fluids are a consequence of their physical properties. Cryogens are gases liquefied at very low temperature. For example liquid helium and liquid nitrogen have boiling points respectively at -269 ^{o}C and -196 ^{o}C. The extremely low temperature is a potential risk for cold burns, frostbites and hypothermia.

Colourless and odourless

Cryogens are colourless both in their liquid and gas state with the exception of liquid oxygen that is light blue. Most of them are also odourless. The fact that many cryogens are colourless and odourless makes them impossible to detect and discriminate by eye or by the sense of smell.

Very large expansion rate

All cryogens have a very large expansion rate the volume of gas produced by the boiling liquid is several hundred times larger than the volume of liquid. For example the ratio volume of gas to volume of liquid at 1 bar and 15 ^{o}C is 738 for helium and 1417 for neon.
Because of the large expansion rate the volume of gas produced by evaporation of the liquid is very large. The large volume of gas displaces the air and can considerably reduce the amount of oxygen available. Risk of asphyxiation is particularly important if liquid cryogens are stored or manipulated in a confined space.

Flammable

Liquid hydrogen, methane, ethylene and ethane are flammable and special precautions must be adopted to manipulate, store and transport these fluids.
Most of the commonly handled cryogens are non-flammable and non-explosive, nevertheless liquid helium, nitrogen and neon although inert can encourage combustion. These cryogens because of their very low temperature can liquefy air producing an oxygen-enriched atmosphere in which combustion is easier.

Toxic

Finally some cryogens are toxic. Ozone (O_3), carbon monoxide (CO) and fluorine (F_2) are highly toxic and must be treated with caution. Specific safety measures must be followed when working with these cryogens.

Some of the physical properties of several cryogens are reported in the table on the back of this leaflet.

Health Hazards

Cold burns and frostbites

Cold burns

Exposure of the skin to a cryogenic liquid or its cold vapour/gas can produce skin burns similar to heat burns. The severity of a cold burn depends on the temperature and the time of exposure. Even brief contact with cryogenic fluids can cause cold burns.

Frostbites

Frostbites are caused by prolonged exposure of unprotected skin to cold vapours or gases. Local pain is the warning sign that freezing is taking place, however sometimes the process is painless. Once tissues are frozen no pain is felt and the skin appears waxy and of yellowish colour.

Contact with cold surfaces

If unprotected skin comes into contact with cold surfaces, like non-insulated pipes or vessels, the skin may stick and flesh may be torn off on removal.

Effect of cold on lungs

Patients suffering from bronchial asthma or chronic obstructive lung diseases often experience aggravation of bronchospasm on exposure to cold environment. Inhalation of cold mist, gases or vapours from the evaporation of cryogenic liquids worsens the degree of airway obstruction for sensitive patients. Short exposure creates discomfort even in normal subjects and could damage lungs in case of prolonged exposure.

Hypothermia

Exposure to low air temperatures can cause hypothermia. Hypothermia is a condition associated to the decrease of body temperature below 35 °C. The susceptibility of a person to hypothermia depends on the temperature, the exposure time and the person's physical conditions (older people are more likely to succumb). Typical symptoms of hypothermia are mild to strong shivering, muscle mis-coordination, inability to use hands, stumbling, mild confusion, difficulty in speaking and amnesia. When the body temperature goes below 33 °C the victim could get unconscious or asleep and after some time could fall into coma.

Asphyxiation

As mentioned above cryogenic liquids have a very large expansion rate. The large volume of gas obtained by the evaporation of the cryogenic liquid displaces air and can considerably reduce the amount of oxygen available.
Asphyxia occurs when the atmosphere contains less than 19% of oxygen by volume. Several stages and symptoms of asphyxia can be recognized depending on the oxygen concentration. In sudden asphyxia, inhalation of a gas containing practically no oxygen brings to immediate unconsciousness. The victim falls as if struck down by a blow on the head and may die in a few minutes.
Typical symptoms of oxygen deficiency are reported in the table below and go from pulse rate acceleration, difficulties in muscular coordination, false judgements, nausea and vomiting, to incapacity to walk and convulsive movements. Oxygen concentration below 8% may produce permanent damage to the brain.

Symptoms of oxygen deficiency (oxygen concentration in %) :	
19% - 15%	Pronounced rise of reaction time
15% - 12%	Deep breaths, fast pulse, coordination difficulties
12% - 10%	Vertigo, false judgement, lips slightly blue
10% - 8%	Nausea, vomiting, unconsciousness
8% - 6%	Death within 8 minutes, from 4-8 minutes brain damages
4%	Coma within 40 seconds, no breathing, death

Toxicity

Ozone (O_3), carbon monoxide (CO) and fluorine (F_2) are highly toxic.
Exposure to concentrations of ozone in excess of several tenths of a ppm can cause headaches, dryness of the throat and of the mucous membranes of eyes and nose. Concentrations over 50-60 ppm are immediately lethal to humans. The maximum permissible O_3 concentration is 0.1 ppm.
Carbon monoxide is hazardous if inhaled. Exposure to CO for half-hour at a concentration of 1000-2000 ppm produces slight heart palpitations and headache, nausea might be experienced after two hours of exposure. Inhalation of a concentration of 4000 ppm can be fatal in less than one hour. The maximum permissible CO concentration is 30 ppm.
Fluorine presents a hazard either by inhalation or by contact with the skin. At a concentration of 50 ppm breathing can be impossible without respiratory equipment and at 100 ppm, skin irritation occurs. The maximum permissible F_2 concentration is 0.2 ppm.

Thermal radiation burns

Exposure to thermal radiation due to the combustion of flammable cryogenic gases can produce first, second or third degree burns. In a first-degree burn only the outer layer of the skin, the epidermis, is affected. In a second-degree burn all of the epidermis and a significant part of the skin deeper layer, the derma, are destroyed. In a third-degree burn all of the epidermis and derma are destroyed.
The degree of severity of a burn depends on the combustion temperature of the gas-air mixture, the distance of the victim from the heat source and the time of exposure.
As an example, exposure to hydrogen flames at a distance of 55 m from the source for more than 30 seconds can produce a second-degree burn.

Blast/explosion injuries

A blast is a consequence of a confined combustion of a flammable gas. A leak of a flammable cryogenic fluid in a confined and not well-ventilated space is extremely dangerous because the flammable gas-air mixture would cumulate in the area. If the gas mixture is ignited a large overpressure is produced with dramatic consequences. An overpressure of 1 psi (about 70 mbar) is enough to knock down a person and an overpressure of 5 psi (about 350 mbar) would damage the eardrums.

Hazards related to material properties, refrigerant properties and condensation mechanisms

Brittle fractures

Some properties of materials can change significantly with temperature. At cryogenic temperatures even relatively low levels of stress or shocks to the material may result in brittle failure. Fractures and cracks cause spills and leaks of the cryogenic liquid and gas.
Common materials such as alloy steels and carbon steel become brittle at low temperature. Materials suitable for cryogenic service are for example copper, nickel, all copper-nickel alloys and aluminium.

Thermal contraction leaks

Cooling down a material from room temperature to cryogenic temperatures causes a significant thermal contraction. For example going from ambient to cryogenic temperatures iron-based alloys contract of about 0.3 % while many plastics well over 1%.
A very large stress is produced at the joints of rods or pipes of a cryogenic system if these are not allowed to contract freely when cooled down. Such stresses might result in broken joints or cracks along the pipe that would produce gas or liquid leaks.
Thermal stress can be reduced and controlled by choosing materials according to their expansion coefficient and thermal conductivity. The selection of operating parameters is also very important to limit thermal stress. A low cooling rate reduces thermal contractions and avoids excessive stress to the material.

Overpressure

The normal heat inleak through the insulated walls and pipes of the storage vessel raises the temperature of the cryogenic liquid. As the temperature rises, the liquid evaporates and the pressure inside the vessel increases.
Overpressure could be caused by:

- a failure of the protection systems such as relief valves and rupture disks
- the loss of thermal insulation
- a fast cool down of a component or instrumentation
- overfilling cylinders with the liquid cryogen

A pressure build up may produce burst with the sudden release of large quantities of cold liquid and gas as well as projection of mechanical parts.

Combustion due to flammable cryogens

Hydrogen, methane, ethylene and ethane are flammable. Under proper conditions the gases of these flammable fluids burn in two different ways: deflagration and detonation.
Confined deflagrations/detonations can build up enough pressure to produce considerable damage to infrastructures and seriously harm people. For example in a confined deflagration of a hydrogen-air mixture a multiplication factor of 8 of the initial hydrogen-air pressure should be considered. In a deflagration if the hydrogen-air mixture is initially at 1 atm, the pressure of the mixture increases up to 8 atm. A multiplication factor of 15 should be considered for a detonation.

Combustion due to oxygen-enriched atmosphere

Oxygen is not itself flammable but supports combustion. Combustible materials in presence of oxygen-enriched atmosphere ignite more easily, burn much more vigorously and can react explosively. Materials normally non-combustible in air such as stainless steels, mild steel, cast iron and cast steel, aluminium and zinc become combustible in oxygen-enriched atmosphere.
Porous materials where oxygen is easily absorbed, flammable liquids and gases, bitumen based substances and hydrocarbon-based oils and greases should not be admitted nearby liquid or gaseous oxygen.
Personnel should not enter areas where the atmosphere is rich in oxygen (> 22%). Hair and clothing may become saturated in oxygen and burn violently if ignited. Clothes contaminated with oxygen should be kept for at least 15 minutes in the open air.

Condensation hazards: overpressure and freezing leaks

Because of their very low temperature almost any cryogen can solidify water or carbon dioxide. The presence of solid particles within a fluid system can cause damage to the system and hazardous situations such as overpressure and leaks.

If air leaks in the vacuum insulation space of a vessel, it will condense on the inner surface of the vacuum space and eventually the moisture present in the air will become ice. If the vessel is then warmed up the liquid air and the ice collected in the vacuum space will evaporate to produce a pressure increase in the vacuum space that could either crush the inner vessel or burst the vacuum jacket. To prevent leaks of air inside a cryogenic system, its internal pressure should be above the external pressure. To protect the system in case of overpressure related to air trapped in vacuum jackets, the design should include relief valves.

If moisture present in the air condenses and freezes inside a pipe, the ice may cause sufficient stress to create cracks and produce leaks. The cryogenic system should be purged before cooling it down to prevent unwanted air condensation.

Condensation hazards: oxygen-enriched atmosphere

Although cryogens such as nitrogen, helium and neon are inert the risk of combustion is still present. These liquids are cold enough to condense air on the external surfaces of vessels and pipes. Liquid air is rich in oxygen and is therefore a fire and even explosive hazard if let to drip on combustible materials such as asphalt or tar.
Air could condensate on the external poorly insulated cold surfaces of a cryogenic system. The liquid air could drip onto equipment or onto the outer shell of the dewar or transfer line producing stress to the material.
Vessels and pipes should be properly insulated with non-combustible material to avoid condensation of air on their cold surfaces. As for flammable cryogens, when using inert cryogens it is recommended storing combustible materials such as oil and grease far away from the operating area.

Precautions during manipulation, transport and storage

Manipulation

Cooling

Objects should be immersed very slowly into liquid cryogens to avoid splashes and spills. Cryogenic gloves and safety glasses or goggles should always be worn. Tangs should be used to place and to remove objects in and out of the liquid.

A cryostat or cylinder should be vented before introducing a measurement probe in the inlet port. If the cryostat is not vented cold gas would abruptly come out of the port as it is opened. Cryogenic gloves and goggles should be worn and the probe should be introduced very slowly in the liquid.

Transfer

Precautions to adopt when transferring cryogenic liquid from one container to another depend on the type of container and the cryogenic liquid. Unless indicated on the manufacturer's manual pressurised and non-pressurised cylinders are designed to store only one kind of cryogenic liquid. Cylinders should never be filled with a cryogen different from the one they have been designed for.

Several containers for cryogenic fluids can be found at the School:

LN_2 static storage tanks	Pressurised liquid cylinders	Non-pressurised liquid cylinders	Flasks
			

Some general basic rules must be followed when transferring cryogenic liquid from one container to another. The following recommendations apply to any type of cryogen:

- Use only proper transfer equipment. Remember that transfer lines must be regularly checked.
- Vacuum insulated transfer lines must be purged every few months, check the manufacturer's instruction manual to know how often the transfer line you have needs to be purged.
- Ensure cylinders and dewars are adequate for the cryogen you use and are clearly labelled.
- Wear personal protective equipment. It is recommended to wear cryogenic gloves, glasses,

goggles or a facemask and a lab coat or apron. Wear closed or work shoes. Open shoes or shoes of porous material such as fabric are not allowed.

- Ensure the receiving vessel is clean and dry to avoid ice to form at the bottom of the vessel.
- Do not leave vessels unattended while filling them.
- Before filling a receiving vessel cool it down by adding a little cryogenic liquid first.
- Do not allow the cryogenic liquid to fall through a distance to reach the receiving vessel.
- When manually pouring liquid into a smaller dewar, ensure that the latter is secured and cannot tip over while filling it.
- Dispense cryogenic liquids slowly into the receiving vessel to minimize splashing, spillage and thermal stress to the vessel.
- Withdrawal devices can be fitted to non-pressurised dewars to make easier to transfer the liquid without the need for tipping and pouring.
- Use only appropriate rods to check the level of the cryogenic liquid in the dewar.
- Never overfill dewars.

Transport

Portable cylinders have wheels and a halo ring on the top. To displace the cylinder the halo ring should be grabbed and the cylinder should always be pushed and never pulled to avoid that it falls on the person making the operation. The halo ring should not be used to roll the cylinder but only to push the cylinder. Once at destination the wheels brakes should be pushed to prevent the cylinder to move freely.

Be aware that cylinders are quite heavy once full. For example, a cylinder of 160 l capacity can weight more than 200 kg when full of LN_2. To transport cylinders of large capacities it is highly recommended that two people are involved in the operation.

Trolley

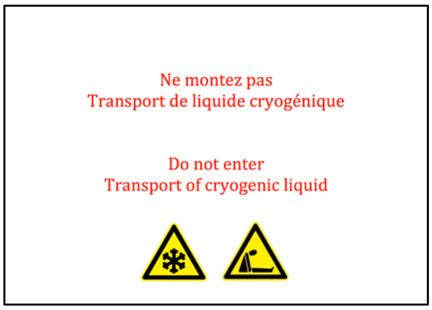
Trolley and tipping stand

Cylinders not equipped with wheels should be moved using purpose designed handling equipment. Trolleys specifically designed for transportation of both pressurised and non-pressurised vessels should be used. Some trolleys are designed with roller base-tipping enabling both transportation and safe pouring.

Transport in goods-lift

At least two people should be involved when a cylinder has to be moved between floors using a goods-lift. Pressurised and non-pressurised cylinders should travel unaccompanied in lifts. The cylinder should be put into the lift and sent to the destination floor where a second person is waiting to collect it. When taking the cylinder in and out of the lift it should be ensured that the lift doors are held open during the process.

People should be denied access to the lift while the cylinder is inside the lift. To prevent people from entering the lift at intermediate floors a chain should be placed at the entrance of the lift and a panel with warning signs should be attached.



A chain and a warning pannel to deny access to the lift to personnel

The panel should indicate that a cryogenic liquid vessel is in transit and that people should not enter the lift.

Few basic recommendations should be followed when moving portable cylinders:

- Plan the route in advance.
- Be aware of your physical capabilities, some cylinders are heavy and need more than one person to be displaced. Plan rest stops if necessary.
- Avoid moving the cylinder through populated work areas.
- Be aware of possible clutter and obstructions.
- Check the floor is solid and even.
- Prefer lifts to stairs when moving cylinders with capacities of several liters.
- Follow the specific instructions when moving cylinders using lifts.
- If you need to use stairs with small hand-held dewars be aware of the risk of spillages if the dewar tips over.
- Do not attempt to catch a cylinder or flask if it falls.
- Ensure that the destination is ready to receive the cylinder with a defined area to store it and appropriate equipment to handle it. Safety gloves and glasses or goggles should be available in the area as well as a recuperation line for cylinders containing LHe.

Storage

Specific storage areas must be assigned depending on the amount of liquid to be stored and the length of time it needs to be stored. Storage areas for cryogens must satisfy several criteria. The key issues to consider are the adequacy of the ventilation to reduce risks of asphyxiation, the type of floor material and the compatibility with other stored substances to reduce risk of combustion.

Cylinders can be stored in laboratory only if justified by a regular and frequent use of the content (on a daily/weekly basis). Personal protective equipment should be available in the laboratory. The internal directive LC-1-2007 “Asphyxia hazard with cryogenic liquids” (3)

indicates that the installation of an oxygen detection system is required if the quantity of liquid stored is above 0.4 l/m^3 for a ventilated laboratory and above 0.3 l/m^3 for an unventilated laboratory. A well-ventilated room has a minimum of five air changes per hour.
Several storage/dispensing areas are at the School:

Outdoor LN_2 storage and dispensing areas	Indoor LN_2 dispensing areas	Indoor LHe delivery areas	Storage in laboratory
			

When storing pressurised cylinders and non-pressurised dewars it is good practice to follow few basic rules:

- Use only cylinders and dewars proper to store cryogens.
- Store the cylinder/dewar below 50 ^oC and in a well-ventilated place.
- Vents and openings must be oriented away from personnel and lab equipment.
- Do not store cylinders and dewars on stairwells.
- Do not store cryogenic liquids with corrosive or flammable chemicals.
- Ensure appropriate hazard warning signs are displayed.

Preventive measures

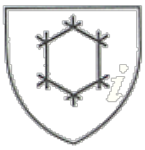
Personal Protective Equipment

Personal protective equipment should always be worn when handling cryogens. The protective clothing is intended to shield from accidental contact with cryogenic liquids and from handling cold surfaces of instrumentations and tools that have been in contact with cryogenic liquids.
When handling cryogenic liquids it is necessary to protect the whole body. Special precaution should be taken for those parts of the body most exposed to the cryogen, such as the hands and those most sensitive to cold, such as the eyes.

Hand protection

Gloves intended to be used with cryogens must satisfy the requirements reported in the norm EN 511 (see table below). According to this norm gloves for cryogens must protect against convective and conductive cold down to -50 °C. Gloves satisfying this norm have a pictogram with a snowflake and three numbers corresponding to performance levels determined by several tests. Thermal insulation, material thermal resistance and water permeability are reported as performance levels and are shown on the glove under the pictogram. According to this norm, cryogenic gloves with performance levels of 2, 3, or 4 should also record at least level 2 in abrasion and tear resistance.
Only cryogenic gloves satisfying the norm EN 511 should be used when working with cryogens. Non-absorbent leather gloves are recommended. Gloves should be a loose fit so that they can easily be removed if liquid should splash onto or into them. Gloves with a wide cuff are not recommended because liquid can easily splash into them.

EN 511



a b c

		Performance level 1	Performance level 2	Performance level 3	Performance level 4
a.	Resistance to convective cold (I_{TR}) (m^2 K/W)	$0.10 \le I_{TR} < 0.15$	$0.15 \le I_{TR} < 0.22$	$0.22 \le I_{TR} < 0.30$	$I_{TR} \ge 0.30$
b.	Resistance to contact cold (R) (m^2 K/W)	$0.025 \le R < 0.050$	$0.050 \le R < 0.100$	$0.100 \le R < 0.150$	$R \ge 0.150$
c.	Water permeability	0 = Water leakage 1 = No water leakage			

Pictogram and performance levels of cryogenic gloves according to the norm EN 511.

Eye and face protection

Glasses

Goggles

Face shield

Eye protection is required at all times when handling cryogenic fluids. Safety glasses, goggles or face shield should always be worn when spraying or splashing of liquid may occur.
A face shield by itself does not provide sufficient protection when there is a high risk of

splashing, for example when pouring a cryogen at the level of the face or when working with a wide-mouth dewar where a high open flow delivery is involved. When carrying out these operations safety glasses or goggles underneath the face shield must be worn.

Body protection

Lab coat

Apron

Clothes with open pockets and turn-ups where liquid could collect should be avoided.
When using liquid oxygen special care should be taken. If oxygen contaminates clothes they can very quickly catch fire even via a very small ignition source like a spark. Clothes contaminated with oxygen should be removed and placed in a well-ventilated area for at least 15 minutes and kept away from any source of ignition.
Clothes should be kept free of oil and grease as these act as fuel for combustion. Woven clothes should be avoided as wool can rapidly become saturated with cold liquid.

When working with cryogenic fluids it is recommended to wear a lab coat or specific aprons. Aprons in leather or made of other materials resistant to cold can be found on the market.

Feet protection

Re-enforced toecap shoes

Closed shoes should be worn to protect feet from spills and splashes. Boots are not recommended as they are more difficult to remove in case liquid enters them. If boots must be worn then trousers should be worn outside them to avoid the entry of liquid. Sturdy shoes with re-enforced toecap are recommended, particularly when displacing cylinders. Open toed shoes, such as sandals, must never be worn under any circumstances.

Ventilation

Ventilation is a key issue when handling and storing cryogenic liquids. Large quantities of cryogenic liquids must be stored in open air or in well-ventilated areas. Small and unventilated rooms should be avoided because gas would accumulate in these rooms as the liquid cryogen evaporates. A well-ventilated laboratory has a number of air changes per hour between 5 and 10.

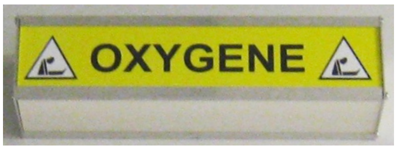
The internal directive LC-1-2007 “Asphyxia hazard with cryogenic liquids” (3) specifies that an oxygen detection system should be installed if the quantity of liquid stored in the laboratory is above 0.4 l/m^3 for ventilated laboratory and above 0.3 l/m^3 for unventilated laboratory.

Detectors and warning signs

Cold hazard warning sign


Wherever cryogenic liquids and gases are used or stored, warning signs should be displayed and in some situations barriers, for example a chain, should be placed to indicate the extent of the hazard.

Oxygen detector



An oxygen detector should be installed depending on the quantity of liquid cryogen stored in the laboratory. The detector is equipped with a visual alarm that becomes active if the oxygen level goes below 19%. If the oxygen level drops below 18% an acoustic alarm is also activated.
The instrument should undergo regular calibration checks and routine maintenance to ensure reliable performance.
A panel indicating “Lab under O2 detection, Evacuate in case of alarm” should be attached to all doors giving access to the laboratory.

Flammable gas detector

A flammable gas detector should be installed in the laboratory when flammable cryogens are used. The gas detection system gives an early warning of the presence of a leakage. In areas where more than one gas is to be detected the instrument should be calibrated for the gas it is least sensitive. Moreover the gases present in the area, other than the flammable gas being detected, should be compatible with the detector catalyst and should not inhibit it.

Toxic gas detector

A toxic gas detector should be installed in the laboratory when toxic cryogens are used. As for flammable gas detectors it is important to ensure that the detector is calibrated for the gas in use and that regular maintenance is provided.

Housekeeping and maintenance

Good housekeeping and regular maintenance are essential to avoid hazardous situations and prevent accidents. Cryogenic cylinders and cryostats should be regularly checked to spot possible damages or malfunctioning of the safety system.

Pressurised cylinders/dewars

- Always read the instruction manual before using the cylinder.
- Regularly check the condition of the vessel and piping. Verify in particular the absence of

frost around the cylinder and the top neck.
- Never contaminate cylinders/dewars/flasks designed to contain a certain type of cryogen with a different cryogen. For example, unless indicated on the cylinder's documentation, liquid nitrogen cylinders should never contain other liquid than nitrogen.
- Always clean and dry dewars and flasks before filling them.
- Cylinders should be modified or repaired only by qualified personnel. Contact the manufacturer if the cylinder is damaged.

Transfer lines
- Regularly verify that the insulation of the transfer line is appropriate. Transfer lines for LHe are equipped with a vacuum insulated jacket that should be regularly pumped to ensure vacuum is adequate. If during the transfer you notice ice around the line, stop the transfer, let the line warm up and proceed to pump out the line with a primary pump. Read the instruction manual to learn how to pump out the transfer line you have.
  Transfer lines for LN_2 are often without a vacuum insulation unless they are several meters long. A large quantity of ice around a not vacuum insulated LN_2 transfer line indicates that the line could be damaged. In this case contact the manufacturer for reparation and do not use the line until it has been repaired.
- Before using a transfer line be sure it is well dry.
- Check for blockages or dust at the inlet and outlet nozzles of the line.
- After use leave the line to warm up to room temperature. Once the line is warm and dry put the protection cup on the inlet and outlet nozzles to keep them clean and to prevent air and humidity to get inside.
- To avoid damaging the line, store it where there is no risk it could fall or get inadvertently hit.

Relief valves/Burst disks
- If valves or burst disks are blocked or damaged they should be cleaned and repaired in the shortest delay because gas could not be released in case the pressure rises.
- Read the instructions in the manufacturer's manual to learn how to clean valves and burst disks.
- Do not try to repair damaged valves or disks but rather contact the manufacturer for replacement or to repair them.

Pressure gauges and liquid level gauges
- Pressure and liquid level gauges should be regularly checked.
- In case of damage or malfunctioning the gauge should be replaced.

Flanges, O-rings and gaskets
- Cryostats are designed with apertures equipped with flanges to connect instrumentation such as vacuum pumps or pressure gauges. Apertures are also foreseen to give access to samples, instrumentation or probes to the coolant. Flanges have O-rings or gaskets to ensure vacuum tightness.
  Flanges, O-rings and gaskets should be cleaned properly using appropriate products. Any trace of grease and dirt should be removed.
- Flanges, O-rings and gaskets should be replaced if damaged.

First aid procedures in case of accident

Treatment of thermal burns

The first aid to provide to a person with a cold or a heat burn injury is very similar.

In case of a cold/heat burn:

1. Call 115 to ask for medical attention specifying the type of burn (cold or heat burn). In case of cold burn specify also the type of cryogen. The intervention team will be there in few minutes.

While waiting for the intervention team to arrive:

2. Cold burn: remove wet clothing but do not try to remove clothing that is frozen to skin. Heat burn: remove burned clothes only if they are not stuck to the skin.
3. Flush with copious amounts of tepid water or immerge the affected area for about 20 minutes in a warm water bath not exceeding 20 °C. Do not hesitate to use the safety showers if the affected area is extended.
4. Cold burn: Do not apply direct heat from blow dryers, radiators or fires.
5. In case water is not available nearby and the affected area is small, use the water of the eye-showers' sprays. If the eye showers are also not available use the hydrogel dressing that is inside the pharmacy box.
6. Cold burn: if the skin is stuck to cold surfaces such as cold pipes, first isolate the source of cold liquid and then pour copious amounts of tepid water until the skin is released.
7. Do not rub or massage the affected area.
8. If feet are concerned with burns, do not allow the victim to walk.
9. Cold burn: keep the victim warm.
10. If possible remove the victim from the hazardous area to prevent further exposure.
11. The intervention team will take care of covering the affected area with sterile dry dressing to protect from infection. The bandage should be loose and should not restrict blood circulation.

Treatment of frostbite

Frostbite occurs when tissues freeze. A prolonged exposure of the skin to cold vapor and gas would constrict blood vessels. The skin would start to freeze and appear waxy and yellow.

1. Call 115 and ask for medical attention.

While waiting for the intervention team to arrive:

2. Bring the victim in a warm place.
3. If the frostbite is at the feet or toes the person should not walk.
4. Gently warm the area in warm water until the skin appears red and warm. The affected person will experience significant pain as the areas are rewarmed and blood flow reestablished.
5. If no water is nearby, warm the area with warm air or with your breath.

6. Do not use direct heat from blow dryers, radiators or fires.
7. Do not rub or massage the skin.

Treatment of splashes in the eyes

If cryogenic liquid or gas have affected the eyes:

1. Call 115 and ask for medical attention.
2. Flush eyes immediately with warm water. Use preferably the eye-shower and rinse for at least 15 minutes.

Treatment of hypothermia

The symptoms of hypothermia go from mild to strong shivering, muscle mis-coordination, inability to use hands and stumbling. The person might look confused and have difficulties to speak.

If a person appears to be suffering from hypothermia:

1. Call 115 and seek immediate medical attention.

While waiting for the intervention team to arrive:

2. Move the victim to a warm place.
3. Wrap the victim in blankets or several layers of clothes to keep warm.
4. Do not use direct forms of heating to warm (radiators or fires).
5. If the victim is unconscious place him/her in the safety lateral position.

Emergencies

Emergency situations require urgent intervention of personnel professionally qualified and trained to respond to the immediate risk to health, life, property or environment. In an emergency situation the treatment of injuries goes often beyond a first aid that an unqualified person could give.

The emergency situations that could develop by the use or storage of cryogens are fire, blast, asphyxiation and intoxication. Intoxication can only be produced by a leak of toxic cryogens, while almost any type of cryogen could produce the other three types of emergencies.
Hereafter are recommendations to prevent and to respond to these emergency situations.

Oxygen deficiency due to leaks or spillages
An uncontrolled release of cryogens due to a leak or spillage of liquid or gas decreases the room temperature to very low values (120K) in few seconds and rapidly reduces the oxygen concentration in the air.

In case of asphyxiation it is very important to act quickly as deprivation of oxygen can have devastating effects on health. Most laboratories are equipped with fixed oxygen detectors. If the oxygen percentage in the laboratory drops below 19% the detector sets off a visual alarm, if it drops below 18% an acoustic alarm is also activated.

In case of a *sudden and uncontrolled release of cryogen*:

1. If you see the warning sign light up or hear the oxygen alarm leave immediately the area and close the door. When exiting the area try to avoid passing through a vapor cloud. If you find yourself in the path of a vapor cloud, hold your breath until you are out of the cloud.
2. Evacuate people from the dangerous area and if possible place a warning sign indicating that entrance to the area is forbidden because of a leak of cryogenic liquid. Stay as far as possible away from the area and preferably go outside the building. Once far from the dangerous area call 115 specifying the type of cryogen causing the spill.
3. If you see in the laboratory an unconscious person and the oxygen alarm is active:

   3.1 Do not enter the room.
   3.2 When calling 115 inform of the presence of a victim of suspected asphyxiation. Indicate the location.

4. Wait for the intervention team outside the building to give further information and the eventual number and location of the victims.
5. Wait until the alarm stops and the intervention team gives you the permission to re-enter the room.
6. Once you are back in the room open windows and doors to allow for sufficient ventilation.

In case of a *small release of cryogen (small leak or spillage)*:

1. Try to limit the spread of the leak only if this is possible without taking risk.

2. Provide good ventilation opening windows and doors.
3. Let the liquid to evaporate.
4. Prevent liquid to enter into sewers, pits and trenches.
5. If you or your colleagues suffer of the early symptoms of asphyxiation such as lack of concentration, headache or vertigo leave the laboratory even if the oxygen alarm is not active.
6. Call 115 immediately and explain you suspect the presence of an asphyxiation risk.

Fire

Although liquid nitrogen, liquid helium and other inert cryogens are not flammable they can support combustion. As very cold these cryogens can condense air and create an atmosphere rich in oxygen. In an oxygen-enriched atmosphere some substances burn much more vigorously or can even react explosively.
It is good practice to store cryogens far from ignition sources. Open flames, welding, smoking and any other obvious ignition sources must be forbidden in areas where cryogens are stored or used.

In case of fire:

1. Call 115 or activate the building's fire alarm system.
2. Evacuate the building through the emergency exits.
3. While leaving the building:

   3.1 Help any person in need of assistance to get out of the building.
   3.2 Close windows and doors.
   3.3 Turn off gas and remove any flammables from hazardous area. Switch off laboratory equipment also in the nearby laboratories.
   3.4 Use fire extinguisher to limit and extinguish fire only if by doing so you do not put yourself in danger. Fire extinguishers are located near every laboratory’s door or in the hallways next to hose cabinets.

4. Once outside the building report to the intervention team any information such as if you saw somebody still inside the building or if particular hazards are present in the laboratories.
5. Wait to go back inside the building until the intervention team gives you permission to do so.

Burst due to overpressure

If cryogens are stored in pressurised cylinders not adequately vented the pressure build up can produce a burst. A burst is an explosion where the stored pressure energy is released without chemical reaction. A burst develops with projection of mechanical parts and ejection of gas/liquid accompanied with a very loud sound of rushing gas.

If an uncontrolled and rapid pressure increase is observed in a cylinder or cryostat and venting fails:

1. Evacuate immediately the area.

2. Call 115 reporting a risk of burst and specify the type of cryogen concerned.
3. If a blast has occurred, assemble the injured people in one area outside the building and inform the intervention team of their number.
4. Wait to go back inside the building until the intervention team gives you permission to do so.

References

1. Frederick J. Edeskuty and Walter F. Stewart (1996). Safety in handling of cryogenic fluids, The international cryogenics monograph series, Plenum press, New York.

2. Safety Panel, British Cryogenics Council (1991). Cryogenics safety manual a guide to good practice, Third edition, Butterworth-Heinemann, Oxford.

3. Internal directive LC-1-2007 "Asphyxia hazard with cryogenic liquids" http://sb-sst.epfl.ch/cryogenic-hazards.

For further information please contact the SB-SST, http://sb-sst.epfl.ch.

	Helium	Hydrogen	Neon	Nitrogen	Argon	Oxygen	Methane	Krypton	Xenon	Ethylene	Ethane
Chemical symbol	He	H_2	Ne	N_2	Ar	O_2	CH_4	Kr	Xe	C_2H_4	C_2H_6
Molecular weight	4	2	20	28	40	32	16	84	131	28	30
Normal boiling point, ^{o}C (K)	-269 (4.2)	-253 (20.3)	-246 (27.1)	-196 (77.4)	-186 (87.3)	-183 (90.2)	-161 (111.7)	-152 (121.4)	-109 (164.1)	-104 (169.3)	-89 (184.6)
Freezing temperature, ^{o}C (K)	-	-259 (14.1)	-249 (24.5)	-210 (63.3)	-189 (84.0)	-219 (54.8)	-183 (90.6)	-169 (104.2)	-140 (133.2)	-169 (104.2)	-183 (89.9)
Critical temperature, ^{o}C (K)	-268 (5)	-240 (33)	-229 (44)	-147 (126)	-122 (151)	-119 (154)	-82 (191)	-63 (210)	17 (290)	10 (283)	32 (305)
Critical pressure, bar	2.3	13.4	27.8	34.5	49.5	51.4	47	56	60	52.5	49.7
Expansion ratio – increase in volume as liquid at 1 bar boils to gas at 1 bar, 15 ^{o}C	738	826	1417	678	820	843	626	677	556	489	437
Density of saturated liquid at 1 bar (kg m^{-3})	125	70	1200	804	1390	1142	424	2400	3100	565	546
Relative gas density (referenced to dry air at 1 bar, 15 ^{o}C, density 1.21 kg m^{-3})	0.14	0.07	0.70	0.98	1.40	1.12	0.56	2.93	4.61	0.97	1.05
Latent heat of vaporisation at 1 bar (cooling potential of phase change) (h_{fg} $kJkg^{-1}$)	23.9	451.9	87.0	199.2	162.7	212.9	512.4	108.0	96.2	483.4	488.3
Fire/explosion hazard	no	flammable	no	no	no	yes	flammable	no	no	flammable	flammable
Air liquefaction hazard	yes	yes	yes	yes	no	no	no	no	no	no	no

Note: With the exception of liquid oxygen, which is light blue, all the liquid cryogens are colourless.
With the exception of C_2H_4 and C_2H_6, which have a slight anaesthetic effect, all the cryogens listed are considered non-toxic.

Reference: Cryogenics safety manual, a guide to good practice. Safety Panel, British Cryogenics Council, Third edition, 1991.