WHS Guidelines - Liquefied Gases

1. Scope

These guidelines are applicable to all environments that utilise liquefied gases. This document specifically refers to liquid nitrogen but may also be applicable to other liquefied gases. The purpose of this document is to detail minimum requirements for working with liquefied gases, to list common hazards and mitigation strategies and to provide information to assist personnel when conducting risk assessments and developing proper and safe procedures and appropriate documentation.

2. Introduction

When conducting risk management activities, people with WHS responsibilities should:

- Ensure that minimum requirements are in place
- Using the hazard summary table below and their experience and expertise, identify any other hazards in the environment and implement appropriate mitigation strategies

3. Definitions

Liquid nitrogen is a colourless, odourless liquid of boiling point -196°C, density 0.8 kg/litre, with very low viscosity. As the liquid boils at standard ambient temperature and pressure, the expansion ratio (the gas factor) is approximately 700. The resulting cold gas is heavier than air, so it accumulates at ground level.

4. Minimum Requirements

People to receive training in the safe filling, transport and use of liquefied gases based on risk assessment.

5. Hazards Summary Table

Hazard	Possible consequences	Mitigation Options
Asphyxiation	Serious injury or death	– Use small enough quantities such that >18.5 vol% oxygen will be maintained even in a worst case spill (see Appendix 1 for calculations) – Minimise available quantities and use in largest possible spaces – Install oxygen monitoring equipment – Improve ventilation

		– Restrict access to confined spaces incl. lifts and enclosed vehicles
Cryogenic temperatures	Serious injury requiring hospitalisation (Cold burns, Frostbite)	– Design experiments/apparatus to minimise handling and exposure to liquid nitrogen – Use personal protective equipment, especially eye protection. – Use only containers designed for cryogenic liquids
Pressure build up from expanding gas	Serious injury	– Always store such that gas can escape from the storage container – Use only containers designed for cryogenic liquids
Condensation of oxygen	Explosive oxidation, high risk of fire resulting in serious injury	– Avoid cold traps where oxygen could condense – Design experiments/apparatus to reduce exposed cold surfaces where oxygen could condense
Failure due to thermal stress/cycling	Injury requiring medical attention	– Use only containers and equipment designed for cryogenic temperatures. – Wrap or enclose any containers where failure would result in flying fragments

6. Hazard Description

The hazards encountered while using liquid nitrogen are largely related to the large volume of gas produced on evaporation and to the liquid's low temperature. Its very low viscosity means that it rapidly and completely covers surfaces on which it is spilt and it easily penetrates cracks and voids. This means that any spillage on clothing will penetrate much more readily than, say, water. Large spillages on other surfaces may affect areas beneath the surface, by damaging materials or even by causing oxygen depletion in areas remote from the spill.

(a) Asphyxiation

On boiling, nitrogen expands to approximately 700 times its liquid volume. The resulting displacement of oxygen from the atmosphere may be sufficient to cause asphyxiation.

There is no preliminary warning of oxygen deficiency caused by the addition of nitrogen. This is a significant hazard, which has been responsible for a number of deaths in research institutions in the past. Small leaks and spills, or normal boil-off from liquid nitrogen containers will generally not significantly lower available oxygen but may still carry a risk of asphyxiation.

Confined spaces (small poorly ventilated rooms, lifts, enclosed vehicles etc) and larger quantities of liquid nitrogen significantly increase asphyxiation risk.

The risk of asphyxiation must be assessed wherever liquid nitrogen is used or stored, taking into account the volume present in relation to the room volume, the likelihood of leakage or spillage, the normal evaporative losses that occur with liquid nitrogen use and any ventilation arrangements.

Appendix 1 shows how to calculate the oxygen depletion arising from normal evaporative losses and from spills. As an approximation, if the volume of nitrogen gas (m^3) produced from the complete loss of the contents of the largest container in the room is > 0.15 x room volume (m^3), then this corresponds to an oxygen content of around 18 vol % (air normally contains 21 vol % oxygen) and further action must be taken to control the risk of asphyxiation.

The physiological effects of reduced oxygen are shown in the following table. Note that exposure to an atmosphere containing less than 18 vol % oxygen poses a significant risk.

O2 (vol %)	Effects & symptoms
18-21	No discernible symptoms can be detected by the individual
11-18	Reduction of physical and intellectual performance without the sufferer being aware
8-11	Possibility of fainting within a few minutes without prior warning. Risk of death below 11 vol%
6-8	Fainting occurs after a short time. Resuscitation possible if carried out immediately.
0-6	Fainting almost immediate. Brain damage may occur, even if resuscitated quickly

In order to control the risk of asphyxiation, the following conditions should be met for rooms where liquid nitrogen is stored or used.

They should be sufficiently well ventilated, or sufficiently large, to ensure that the oxygen concentration does not fall below 19.5 vol % due to the routine conditions of use, i.e. due to:

- the normal evaporation losses from all liquid nitrogen containers in the room
- the evaporation caused by filling the largest container from a warm condition.

In addition, the loss of the entire contents of the largest container immediately after filling from a warm condition should not cause the oxygen concentration to fall below 18 vol %.

In most rooms, natural ventilation will generally provide around one air change per hour. For basement rooms or where there are well-sealed windows, less than half an air change per hour will be achieved.

Cold nitrogen gas accumulates at low level, so basement rooms, rooms with ventilation openings only at high level, or rooms with floor ducts or pits may pose particular danger in the event of a spill. Where natural ventilation openings are provided, they should be at both high and low level and ideally have a total area of around 1% of the floor area. Where mechanical ventilation is provided, then air should be extracted from low level and supplied at high level.

Where ventilation is insufficient to control the build-up of nitrogen gas, or where leaks or spills would reduce the oxygen content to below 18 vol %, then fixed oxygen monitoring equipment must be used. Care should be taken in placing the oxygen sensors in order to avoid persistent false alarms caused by nuisance triggering (e.g. by direct exposure to gas issuing from containers as they are being filled).

This equipment normally has two alarm levels:

- the upper level should be set at 19.5 vol % O_2 (if this alarm is triggered, then there should be urgent investigation and corrective action)
- the lower level should be set at 18 vol % O_2 (if this alarm is triggered, then the area should be evacuated immediately).

Alarms must be visible and/or audible both inside and outside of the area monitored, in order to give adequate warning of oxygen depletion.

In some circumstances, personal oxygen monitors may usefully supplement fixed ones. All oxygen monitoring equipment must be installed, operated, serviced, and calibrated in line with the manufacturer's instructions. (Users should be aware that the working life of the common electrochemical cell oxygen detectors is only about one year).

(b) Cold burns and frostbite

Skin contact with liquid nitrogen or cold nitrogen gas may cause severe cold burns, comparable with those caused by boiling water. Unprotected skin may freeze onto surfaces cooled by the liquid, causing severe damage on removal. Prolonged skin exposure to cold may result in frostbite, while prolonged inhalation of cold vapour or gas may cause serious lung damage.

The eyes are particularly susceptible – even small splashes of liquid nitrogen, or short exposures to cold vapour or gas, may cause instant freezing of eye tissues and permanent damage.

It is important to note that personal protective equipment such as gloves and footwear can increase the severity of injuries since larger spills can become trapped, thus causing more severe cold burns. In other instances however, personal protective equipment is effective in preventing cold burns. The fundamental principle for selection of personal protective equipment is that it should prevent significant quantities of liquid nitrogen from touching the skin and eyes. Personal protective equipment should not allow fluids to collect on or within them or if it does, the item must be easy to remove quickly.

(c) Explosions due to trapped, expanding gas

If liquid nitrogen is trapped inside a container that is sealed, then expansion on warming above -196°C may cause an explosion, giving rise to danger from contamination by the vessel's contents as well as injury from fragments of the vessel itself.

This is most likely to happen if sample storage vials have been immersed in liquid nitrogen. The shrinkage and embrittlement of materials at this temperature renders any sealing system ineffective and the relatively low surface tension of liquid nitrogen also makes it likely to seep into the vial.

Vessels may also become sealed due to ice plug formation (e.g. in the necks of dewars where the wrong type of stopper has been used, or on the pressure relief devices of dewars stored in damp conditions). Pressure rise may cause the plug to be ejected, or the vessel may rupture.

If glass domestic vacuum flasks are used for liquid nitrogen, its low viscosity may allow it to penetrate the seal between the glass inner and the outer casing, causing an explosion as it warms and expands. Glass domestic vacuum flasks must not be used for liquid nitrogen.

(d) Condensation of liquid oxygen

The boiling point of oxygen is -183°C; therefore liquid oxygen may condense in open containers of liquid nitrogen or in open vessels cooled by liquid nitrogen (e.g. cold traps). Liquid oxygen will accumulate if the liquid nitrogen is constantly replenished, so this type of open cooling system should be avoided where possible. The unsuspected presence of liquid oxygen may give rise to explosions caused by increased pressure if the vessels are subsequently sealed and allowed to warm up. If oxidisable material is present, then liquid oxygen may react explosively with it.

(e) Effects on materials

Many materials become brittle when cooled by liquid nitrogen and may be irreparably damaged. Other materials (e.g. glass dewars) may fail due to temperature stresses. Glass dewars should be enclosed in a metal can or wrapped in tape to give protection against flying glass fragments in the event of such failure.

Use only articles or materials designed for use with liquid nitrogen. Glass domestic vacuum flasks must not be used as they may fail due to thermal shock on filling.

7. General guidelines for small-scale use

(a) Liquid nitrogen containers

Generally speaking, in quantities up to about 50 litres, liquid nitrogen is stored and distributed in simple open-topped vessels, designed to operate at atmospheric pressure ("tulips" or dewar flasks). They are of lightweight construction and should be handled with care to avoid damage to the insulation. The smaller flasks may be easily knocked over.

Larger quantities (up to 250 litres) are generally held in transportable liquid cylinders that may be designed to deliver liquid or gas. They operate at above atmospheric pressure, so they are fitted with safety devices to allow them to vent excess pressure. The manufacturer's recommended intervals for inspection and replacement of the safety devices must be observed. Care must be taken to ensure that any venting takes place safely (as supplied, many such cylinders have safety devices discharging horizontally at eye level) and venting may need to be directed to a safe place outside of the storage area. Transportable cylinders should be handled with care. In particular, trolleys used for moving them, or the trolley bases fitted to some cylinders, must be suitably designed and in good condition to avoid accidents resulting in the cylinder tipping over.

Users should be alert to the signs of insulation failure (the need for frequent topping-up, or excessive condensation on the dewar) as the high boil-off rate increases the risk of oxygen depletion.

(b) Labelling

Liquid nitrogen containers should be clearly labelled showing basic safety-related information.

(c) Filling

Only those who have been suitably trained should fill dewars using a hose from a transportable container or bulk tank. This is a potentially dangerous operation and appropriate PPE must be used. Care must be taken to secure the hose, to purge the line of excess moisture or dust, and to initiate the fill slowly. If an excessively high fill rate allows an unsecured hose to whip out of the dewar, then the situation may rapidly get out of control, with a high probability of injury or death from cryogenic burns and asphyxiation.

(d) Handling

Dewars should be handled with care and not 'walked', rolled or dragged along the floor - rough handling may damage them, as may severe impacts. Manual handling assessments will be needed for larger dewars (say > 20 litres) and these may identify a need for trolleys or tipping trolleys. Stairs and doorways present an added risk of spillage due to tripping, or colliding with someone. If a large dewar (say > 20 litres) must be carried on stairs, then two people should carry it and the use of additional body protection (e.g. an apron) is recommended.

(e) Lifts

Liquid nitrogen must not be transported in occupied lifts, because of the danger of asphyxiation in the event of a leak or spill, especially in the event of a lift breakdown. Appendix 2 provides instructions for transporting liquid nitrogen in occupied lifts.

(f) Transport

For similar reasons, liquid nitrogen must not be transported in a closed vehicle such as a car or van.

(g) Sample storage containers

Users should be aware that there is an oxygen-deficient atmosphere inside large storage containers. Care must be taken to ensure that people retrieving samples cannot lean over the containers in such a way that they might breathe this atmosphere and collapse into or over the container, resulting in asphyxiation.

8. Appendix 1 – Calculating Oxygen Depletion

Assume the room is a sealed environment. Measure room dimensions and calculate the volume in m^3

Add the total volume of all liquid nitrogen containers in litres

Use the following formula or spread sheet located at here to calculate oxygen percentage in room after worst case spill.

Oxygen % after worst case spill = $\{(V_{room} - 0.6823V_{nitrogen}) \text{ X } 20.95\% \} / V_{room}$

Sample calculation for A28 Rm 410

Room volume: 10.8 X 4.9 X 3.1 = 164 m^3

Volume of liquid nitrogen: 10 L

Oxygen % after worst case spill: 20.08% Classified as SAFE.

9. Appendix 2 – Procedure for using the Lift

Personnel must never under any circumstances travel in the lift with liquid nitrogen.

To move liquid nitrogen between floors, load into lift just inside the door and attach a sign:

LIQUID NITROGEN
DO NOT ENTER LIFT
(Asphyxiation Hazard)

Go to destination floor (preferably have another person waiting to receive) and unload lift.