THE UNIVERSITY OF QUEENSLAND
AUSTRALIA
OH&S
Occupational Health & Safety Unit

Liquid Nitrogen: Guidance for Safe Storage and Handling

Introduction

Cryogenic fluids such as liquid nitrogen are widely used throughout the University of Queensland for various tasks. The nature of cryogenic liquids, the very reason for which they are generally used, causes significant risks to the health and safety of persons who may be exposed to them.

There have been several incidents that have resulted in fatalities due to nitrogen exposures. In these incidents, asphyxiation is usually sudden. The victims inhale air with little or no oxygen content causing immediate collapse into a layer of dense, cold, nitrogen enriched air. Unconsciousness followed rapidly by death is inevitable without immediate rescue and resuscitation. Rescue attempts often result in the rescuers being overcome as well if not conducted carefully.

An example of one such incident in Australia occurred at the Australian Animal Health Laboratory where a staff member entered a sample storage room which had become filled with nitrogen gas that had evaporated from liquid nitrogen used to cool the contents of cabinets. A combination of the ventilation system failing and inadequacies in relation to staff being alerted to, and understanding the seriousness of the failures, led to the tragedy (for further information on this incidents, see http://www.csiro.au/index.asp?type=faq&id=Fatalitylessons).

This guideline will provide information on methods to minimise the likelihood of injuries and illnesses occurring from the use and storage of liquid nitrogen. This guideline has been developed to meet selected criteria of *AS/NZS 2243.2-1997: Safety in Laboratories – Chemical Aspects*; and *AS1894-1997: The Storage and Handling of non-flammable cryogenic and refrigerated liquids*.

Hazards and Risks

The hazards arising from the use of liquid nitrogen are;

- Asphyxiation in oxygen deficient atmospheres – if vented into a closed space, liquid nitrogen will vaporize, displacing oxygen and possibly cause asphyxia.

- Combustion and explosion hazard from oxygen enrichment of atmosphere – liquid nitrogen can condense air from the atmosphere, which can lead to production of liquid containing a higher oxygen content than that of normal air. This higher oxygen content increases the combustibility of many materials, creating potentially explosive conditions.

- Cold burns, frostbite and hypothermia – the extremely low temperature of liquid nitrogen (liquid nitrogen boils at -195° C) means that liquid, cold vapour or gas can produce serious skin burns. Objects and uninsulated items of equipment can stick to skin, and flesh may be torn on removal. Cold vapour or gas may cause frostbite given prolonged or severe exposure of unprotected body parts. Transient exposure to very cold gas produces discomfort in breathing and can provoke an attack of asthma in susceptible individuals.

- Over pressurisation from the large volume expansion of the liquid – boiling of liquid nitrogen within a closed system increases pressure (gaseous nitrogen occupies up to 682 times the volume of liquid nitrogen). For example, if liquid nitrogen enters sample vials during storage, the vials when removed from the liquid nitrogen can become rapidly over pressurized with the risk of explosion of the vial.

- Embrittlement – Liquid nitrogen can cause many common materials such as carbon steel, plastics and rubber to become brittle, or even fracture under stress. Liquid nitrogen must not be disposed of down the drain, as piping in laboratory sinks may not be able to withstand cryogenic temperatures.

The expected exposure routes for liquid/gaseous nitrogen are inhalation and skin exposure (ingestion of liquid nitrogen is considered unlikely).

Controlling Risks

If the use of liquid nitrogen is necessary, the risks must be appropriately assessed and controlled to eliminate or reduce the likelihood and severity of injuries and illness to an acceptable level. It is necessary to ensure that liquid nitrogen is appropriately stored, moved and used. It is also important to have an emergency response plan and personnel trained to effectively carry it out safely.

The risk assessment should consider at least the following four situations;

1. Normal evaporative losses .
2. Filling losses – normally assumed to be about 10% of the vessel's capacity.
3. Spillage of the vessel's contents.
4. Spillage of the vessel's contents immediately after filling – loss is equivalent to 110% of the vessel's capacity – 10% filling loss + 100% of contents.

Storage of liquid nitrogen

Liquid nitrogen should only be stored in containers specifically designed to contain cryogenic fluids. Domestic vacuum flasks should not be used. Dewars and pressurized vessels specifically designed for storage of liquid nitrogen, and samples, are the most commonly used containers for the storage of liquid nitrogen throughout the University of Queensland. A dewar is a double walled flask with an open neck which freely vents to atmosphere and is not at pressure. A pressurized vessel is generally of larger capacity (over 50 litres) and does not freely vent but has relief valves and vents.

All liquid nitrogen containers should be stored:

- in a stable manner and on a sturdy surface; and
- in a position that does not restrict access and egress; and
- in a position where they are unlikely to be knocked by persons or other equipment.

The quantity of liquid nitrogen permitted to be stored in an area depends on the volume and ventilation of the area. Areas with good natural ventilation are preferable for storage and decanting tasks because spills, splashes and evaporation are less likely to cause an oxygen deficient atmosphere. Cryogenic fluids should not be stored or used in an office.

Where liquid nitrogen is used in laboratories with limited or no natural ventilation, only limited quantities can be safely used. It follows that in a larger or better ventilated laboratory, a larger quantity of liquid nitrogen can be used safely. If it is necessary to store and use larger quantities of liquid nitrogen however, a low oxygen sensor may be needed.

A low oxygen sensor will alert persons when there is an oxygen deficient atmosphere in the room. If a low oxygen alarm is activated, the room should be evacuated and security called. The minimum acceptable concentration of oxygen in a room's atmosphere is 18 percent (NOHSC, 1995). However, the goal should be to maintain oxygen concentrations above 19.5%.

The risk of asphyxia 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. Some examples of oxygen depletion due to evaporation and spills from common liquid nitrogen dewars are shown below (See appendix A for formula and calculations).

Example 1

Laboratory size (metres)			Dewars			
Width (metres)	Height (metres)	Length (metres)	Size (Litres)	Quantity	Brand	Evaporation Rate (Litres per day per dewar)
6.0	3.0	6.0	30	2	MVE	0.22
			50	1	MVE	0.49

Total oxygen concentration in laboratory after normal evaporative and filling losses*:	19.5% (borderline – low oxygen alarm should be fitted).

* Assuming 6 air changes per hour (considered the minimum rate in laboratories – many laboratories will have a higher air flow rate than this)

Example 2

Laboratory size (metres)			Dewars			
Width (metres)	Height (metres)	Length (metres)	Size (Litres)	Quantity	Brand	Evaporation Rate (Litres per day per dewar)
9.0	2.4	6.0	30 50	4 1	MVE Wessington Cryogenics	0.22 1.10

Total oxygen concentration in laboratory after normal evaporative and filling losses*:	19.1% (unacceptable – implement control measures to increase oxygen concentration).

* Assuming 6 air changes per hour (considered the minimum rate in laboratories – many laboratories will have a higher air flow rate than this)

Example 3

Laboratory size (metres)			Dewars			
Width (metres)	Height (metres)	Length (metres)	Size (Litres)	Quantity	Brand	Evaporation Rate (Litres per day per dewar)
3.0	2.4	5.0	10	2	MVE	0.18

Total oxygen concentration in laboratory after normal evaporative and filling losses*:	20.2% (acceptable)

* Assuming 6 air changes per hour (considered the minimum rate in laboratories – many laboratories will have a higher air flow rate than this)

If the oxygen concentration in the Laboratory is:

- Greater than 19.5% - it is acceptable.
- Between 18% and 19.5% - it is unacceptable. Implement control measures to increase oxygen concentration (consider controls such as increasing ventilation and decreasing the quantity of liquid nitrogen used in the laboratory). A low oxygen alarm should be installed.
- Less than 18% - it is unacceptable – no person should enter the room without air supplied breathing apparatus (generally only emergency services personnel). If the room is to be kept at this concentration, a low oxygen alarm should be interlocked to the door to prevent access by unauthorized personnel.

Regardless of oxygen concentration, the University requires that rooms containing more than 50 litres of liquid nitrogen (whether in pressurized vessels or dewars) should have a low oxygen alarm fitted to alert in the event of liquid nitrogen spills, and liquid or gas escapes.

Specific ventilation controls include:

- Vents and relief valves of pressurized liquid nitrogen vessels should discharge to a safe place (not impinge on people, plant or structures) and should be connected to an extraction system that exhausts to a safe external location or recovery system.
- Where processes generate significant quantities of nitrogen gas, extraction ventilation should be used to remove nitrogen gas from areas where it can affect persons and exhaust it to a safe external location or recovery system.

Moving containers of liquid nitrogen:
If containers of liquid nitrogen are to be transported by vehicle, a dry shipper should be used. Under no circumstances should liquid nitrogen be transported in an enclosed vehicle – i.e. there are no persons enclosed in the same cabin in which liquid nitrogen is being transported. A utility may be used as long as the dewar is restrained

For shifting liquid nitrogen containers within and between buildings, a dewar on wheels or suitable trolley should be used. Goods lifts should be used where available to move containers between floors. If a goods lift is not available, arrangements should be made so that no persons accompany vented dewars in a passenger lift - lock out mechanisms or out of hours shifting of liquid nitrogen may be appropriate under these circumstances.

Filling operations:
Only trained personnel should perform liquid nitrogen filling and transferring tasks. Controls should be implemented to minimize both the quantity and likelihood of spills and splashes, as well as exposure to escaping liquid and gases. Controls could include using liquid nitrogen pumps, wearing normal personal protective equipment and ventilation. Valves must be opened slowly to allow for thermal effects on fittings and gas escape due to evaporation.

Use of liquid nitrogen:
Effective control options must be implemented to ensure the use of liquid nitrogen is safe. Control options in the engineering category are preferable as they reduce the risk at its origin. Administrative controls and the use of personal protective equipment only reduce the risk for the person and rely on their correct implementation and use.

It is particularly 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.

It is therefore necessary to carefully consider the tasks performed using liquid nitrogen, possible mechanisms of injuries and illnesses, the quantities persons might be exposed to, then select and implement the most appropriate control measures.

- Engineering controls
    - Enclosed systems;
    - Natural or forced ventilation;
    - Use a liquid nitrogen pump to decant the substance rather than pouring;
    - Use of equipment designed for use with cryogenic fluids;
    - Inspection and maintenance program to ensure dewars, cylinders and equipment are in good condition.
    - Low oxygen alarms;
    - Interlocking doors;
    - Emergency equipment such as safety shower and eye wash unit;

- Administrative controls
    - Training of persons using liquid nitrogen;
    - Safe working procedures;
    - Supervision and not working alone;
    - Limited access to hazardous areas;
    - Emergency response procedure;
    - Good housekeeping;
    - Good personal hygiene;

- Selection and use of personal protective equipment
    - Full face shield;
    - Clean and dry cryogenic gloves for handling cold items or thick leather gloves to protect against splashes and for handling cold items (gloves should be loose fitting and easy to slip off in the event of a spill which enters the glove);
    - Closed in footwear that can be removed easily in the event of a spill;
    - Long pants should be worn (on the outside of footwear).
    - Air supplied breathing apparatus will be needed for work in an oxygen deficient atmosphere (i.e. less than 18%). The University of Queensland recommends that persons do not enter rooms in which the oxygen concentration is less than 19.5%.

Emergency response:
If a significant quantity of liquid nitrogen has escaped, or been spilt, the area affected will not contain adequate oxygen to support life. The area should be immediately evacuated. Security and the Workplace Health and Safety Officer for the area should be contacted.

If a person is showing symptoms of mild or severe asphyxia, they should be moved to an area with fresh air. If they are not conscious, security should be called immediately and resuscitation started by a qualified first aid officer or physician.

Cold burns from liquid nitrogen should be immediately and continually flushed with tepid or unheated tap water.

Professional medical advice should always be sought urgently for significant cold burns and asphyxia. Persons affected may need urgent medical treatment at a hospital.

References / Further Information

National Occupational Health and Safety Commission, 1995. Guidance note on the interpretation of exposure standards for atmospheric contaminants in the occupational environment [NOHSC:3008(1995)]. Australian Government Publishing Service: Canberra.

Standards Australia (1997): AS1894-1997: The storage and handling of non-flammable cryogenic and refrigerated liquids. Standards Australia: Sydney.

Standards Australia (1997): AS/NZS 2243.2-1997: Safety in laboratories – Chemical aspects. Standards Australia: Sydney.

Appendix A: Oxygen Depletion Calculations

To determine oxygen concentrations after normal evaporative and filling losses, the following calculations can be used.

Step 1: Normal evaporative losses.

(a) $$N_E = \frac{2 \times 682 \times (D_N \times D_E)}{24 \times 1000}$$

(b) $$A_D = \frac{N_E}{R_v \times R_A}$$

(c) $$O_D = 0.21 \times 100 \times A_D$$

Where:

- N_E is the nitrogen evaporation rate (in m^3h^{-1}).
- 2 safety factor to allow for the deteriation of the dewar's insulation.
- 682 expansion factor for liquid nitrogen to gaseous nitrogen.
- D_N is the number of dewars.
- D_E is the evaporation rate from the dewar (L/day) (obtained from the supplier of the dewar).
- A_D is the fractional reduction in the air concentration due to the conversion of liquid nitrogen to gaseous nitrogen.
- R_V is the volume of the room (m^3).
- R_A is the number of room air changes per hour.

Step 2: Filling losses.

(a) $$O_V = 0.21 \times [R_V - (0.1 \times D_V \times 682 \times 0.001)]$$

(b) $$O_C = \frac{100 \times O_V}{R_V}$$

Where:

- O_V is the volume of oxygen in the room (m^3).
- D_V is the volume of the dewars (L).
- O_C is the oxygen concentration (%)

Step 3: Total oxygen concentration in the laboratory.

$$O_T = O_C - O_D$$

Where:

- O_T is the total oxygen concentration in the room (%)

(Adapted from University of Oxford Policy Statement S4/03.
http:// www.admin.ox.ac.uk/safety/s403a1.shtml accessed 6 Jan 2005)

Example 1:

Step 1 (a) $N_E = \frac{2 \times 682 \times (D_N \times D_E)}{24 \times 1000}\ m^3h^{-1}$

$N_E = \frac{2 \times 682 \times [(2 \times 0.22) + (1 \times 0.49)]}{24 \times 1000}\ m^3h^{-1}$

$N_E = \frac{1364 \times (0.44 + 0.49)}{24000}\ m^3h^{-1}$

$N_E = 0.053\ m^3h^{-1}$

(b) $A_D = \frac{N_E}{R_V \times R_A}$

$A_D = \frac{0.053}{108 \times 6}$

$A_D = 0.000082$

(c) $O_D = 0.21 \times 100 \times A_D$

$O_D = 0.21 \times 100 \times 0.000082\ \%$

$O_D = 0.0017\%$

Step 2: (a) $O_V = 0.21 \times [R_V - (0.1 \times D_V \times 682 \times 0.001)]\ m^3$

$O_V = 0.21 \times [108 - (0.1 \times 110 \times 682 \times 0.001)]\ m^3$

$O_V = 21.1\ m^3$

(b) $O_C = \frac{100 \times O_V}{R_V}\ \%$

$O_C = \frac{100 \times 21.1}{108}\ \%$

$O_C = 19.5\%$

Step 3: $O_T = O_C - O_D$

$O_T = 19.5\ \% - 0.0017\%$

$O_T = 19.5\ \%$

Example 2:

Step 1 (a)

$$N_E = \frac{2 \times 682 \times (D_N \times D_E)}{24 \times 1000} \ m^3h^{-1}$$

$$N_E = \frac{2 \times 682 \times [(4 \times 0.22) + (1 \times 1.10)]}{24 \times 1000} \ m^3h^{-1}$$

$$N_E = \frac{1364 \times (0.88 + 1.10)}{24000} \ m^3h^{-1}$$

$$N_E = 0.113 \ m^3h^{-1}$$

(b)

$$A_D = \frac{N_E}{R_V \times R_A}$$

$$A_D = \frac{0.113}{129.6 \times 6}$$

$$A_D = 0.000145$$

(d)

$$O_D = 0.21 \times 100 \times A_D$$

$$O_D = 0.21 \times 100 \times 0.000145 \ \%$$

$$O_D = 0.003\%$$

Step 2: (a)

$$O_V = 0.21 \times [R_V - (0.1 \times D_V \times 682 \times 0.001)] \ m^3$$

$$O_V = 0.21 \times [129.6 - (0.1 \times 170 \times 682 \times 0.001)] \ m^3$$

$$O_V = 24.8 \ m^3$$

(c)

$$O_C = \frac{100 \times O_V}{R_V} \ \%$$

$$O_C = \frac{100 \times 24.8}{129.6} \ \%$$

$$O_C = 19.1\%$$

Step 3:

$$O_T = O_C - O_D$$

$$O_T = 19.1 \ \% - 0.003\%$$

$$O_T = 19.1 \ \%$$

Example 3:

Step 1 (a)

$$N_E = \frac{2 \text{ x } 682 \text{ x } (D_N \text{ x } D_E)}{24 \text{ x } 1000} \text{ m}^3\text{h}^{-1}$$

$$N_E = \frac{2 \text{ x } 682 \text{ x } (2 \text{ x } 0.18)}{24 \text{ x } 1000} \text{ m}^3\text{h}^{-1}$$

$$N_E = \frac{1364 \text{ x } (0.36)}{24000} \text{ m}^3\text{h}^{-1}$$

$$N_E = 0.020 \text{ m}^3\text{h}^{-1}$$

(b)

$$A_D = \frac{N_E}{R_V \text{ x } R_A}$$

$$A_D = \frac{0.020}{36 \text{ x } 6}$$

$$A_D = 0.000093$$

(e)

$$O_D = 0.21 \text{ x } 100 \text{ x } A_D$$

$$O_D = 0.21 \text{ x } 100 \text{ x } 0.000093 \ \%$$

$$O_D = 0.0020\%$$

Step 2: (a)

$$O_V = 0.21 \text{ x } [R_V - (0.1 \text{ x } D_V \text{ x } 682 \text{ x } 0.001)] \text{ m}^3$$

$$O_V = 0.21 \text{ x } [36 - (0.1 \text{ x } 20 \text{ x } 682 \text{ x } 0.001)] \text{ m}^3$$

$$O_V = 7.27 \text{ m}^3$$

(d)

$$O_C = \frac{100 \text{ x } O_V}{R_V} \ \%$$

$$O_C = \frac{100 \text{ x } 7.27}{36} \ \%$$

$$O_C = 20.2\%$$

Step 3:

$$O_T = O_C - O_D$$

$$O_T = 20.2 \ \% - 0.0020\%$$

$$O_T = 20.2 \ \%$$