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1. **Statement of Purpose**

This guidance is intended to provide information regarding the hazards, risks, and controls primarily associated with the use of liquid nitrogen (LN2), but also for liquid helium (He), liquid carbon dioxide (CO2) or dry ice, and other cryogenic materials (cryogens), necessary for the protection of life and property. The contents of this guidance document should be communicated with all Penn State users of cryogens. In many cases, additional information will be required to address specific processes or operations in which cryogens are being used at Penn State laboratory and facility operations. Finally, the information contained in this document is intended to support the safe and effective storage, use, handling, transportation, and disposal of cryogens.

1. **Introduction**

Cryogens include solids, liquids, and gases with boiling points ranging from minus (–)78.5°C or

(– 109F) for carbon dioxide to –269.9°C or (–454°F) for helium. Commonly used cryogenic liquids (gases maintained in liquid state by low temperature and/or increased atmospheric pressure) used at Penn State facilities include: liquid nitrogen (LN2), liquid helium (He), and liquid carbon dioxide (CO2). Others may include, but are not limited to: liquids oxygen (O2), argon (Ar), hydrogen (H2), and methane (CH4).

Principle hazards associated with cryogens include: cold burns/ freezing, toxicity, and asphyxiation from oxygen displacement, material and construction incompatibility, as well as hazards associated with high pressures, explosions and implosions. These hazards are further described at section 6.0 of this SOP.

1. **Applicability & Scope**

This EHS Standard Guide (SOP) shall pertain to the storage, use/handling, transportation and disposal of cryogenic materials at Penn State facilities.

This SOP is not applicable to flammable liquids that exist as liquids (liquid state at standard temperature and pressure), nor to compressed gases such as: hydrogen, oxygen, nitrogen, acetylene, etc. that are stored and maintained under pressure as gases.

The Penn State Hershey Medical Center and associated facilities are exempted from this SOP, and are covered by separate policies and procedures.

1. **Roles & Responsibilities**
	1. Faculty Administrators, Directors, Managers, Work Unit Supervisors, and Facility Coordinators/Safety Officers are responsible to ensure this SOP is disseminated and/or made accessible to pertinent University faculty, staff and students. Though not presently established as policy, each work unit should reference this protocol as necessary to ensure safe work practices, inspection procedures, training, maintenance, disposal, and transport are completed by pertinent personnel.
	2. Design Teams/Engineers, Facility Coordinators, Safety Officers and/or Principal Investigators who oversee or support academic, research or work operations that use cryogenic equipment and materials within their campus, college, or department should consult EHS for assistance in assessing the relative risk of cryogenic storage and use within their work unit. Refer to the risk assessment tool presented at Appendix A5.
		1. Additional safety reviews should follow any system modification to ensure that no potentially hazardous condition has been overlooked or created, and that updated operational and safety procedures remain adequate.
		2. Key considerations for ensuring safety include:

* + - 1. Protective measures needed for storage and dispensing areas, including exhaust ventilation.
			2. Necessary equipment, personal protective equipment (PPE), and procedures for safe use and handling of cryogenic materials.
			3. Consult EHS when large installations or significant changes are considered.
			4. Conduct departmental inspections to ensure personnel working with cryogenic fluids follow guidelines for safe use, handling, transportation and storage such as those listed in this procedure.

Refer to Appendices A1 – A4 for supporting information.

* 1. Office of Physical Plant Departments such as, but not limited to: Design & Construction, Design Services, Commonwealth Services, Engineering Services, Work Control Center, and Facility Automation Services are responsible for the safe design, installation, commissioning, operation and maintenance of Penn State facilities and laboratories, including pertinent ventilation systems. OPP shall be consulted in accordance with pertinent Penn State policies such as CPD4 for Campus Planning and Design, as may be pertinent to cryogenic storage. Consultation with EHS is strongly advised to ensure a necessary risk assessment has been conducted, and that all necessary equipment planning, installation and maintenance aspects have been safely planned and implemented.
1. **Terms & Definitions**

*Asphyxiant* – any material which reduces the amount of available oxygen for respiration, either by simple displacement or by internal physiochemical reaction.

*Asphyxiation –* to lose consciousness by impairing normal breathing, via exposure/inhalation of a gas or other agent, usually resulting in loss of consciousness and/or death**.**

*Cryogenic liquids –* are gases that exist in liquid state at temperatures between –78.5°C and

–269.9°C.

*Compressed gas cylinder –* any cylinder specifically designed to contain gases under pressure of greater than one atmosphere, and having the capability of dispensing the gas by the means of a control valve mechanism to assure the safe and proper use of the gas at a point of operation.

*Dewar –* An insulated container used especially to store liquefied gases, with a double wall containing vacuum pressure (> 0.5 bar) between the walls and silvered surfaces facing the vacuum. Small hand carried Dewars range in size from 1L capacity to 20L, while large Dewars, typically equipped with their own lockable wheels for ease of transport, can range in size from 20L to 100L.

*Dry Shipper* – Under the International Air Transportation Association (IATA) regulations Packing Instruction 202, a dry shipper is a Dewar that is properly prepared for shipment where all liquid nitrogen is removed and/or fully absorbed by an inner porous material. To meet the “Exception” requirements for shipping, the design of the container must prevent the build-up of pressure within the container, and prevent the release of liquid nitrogen, irrespective of the orientation of the container. *PARTIES MUST CONTACT EHS FOR PROCESSING SHIPMENTS OF DRY SHIPPERS.*

*Hazardous Material Regulations –* The packing and shipping of hazardous materials, such as cryogenic liquids (liquid nitrogen, oxygen, hydrogen, carbon dioxide, etc.),

is regulated by the U.S. Department of Transportation hazardous material regulations at 49 CFR Part 173, the International Air Transportation Association (IATA), the Federal Aviation Association (FAA) and the International Civil Aviation Organization (ICAO). Liquid nitrogen exception requirements are specified at 49 CFR 173.320, and the IATA Packing Instruction 202.

1. **Physical Properties & Hazards Associated with Cryogenic Materials**
	1. Specific Cryogen Properties

**Refer to the subsequent page (Table 6-1) for a list of physical properties of common liquid cryogens.**

**Table 6-1 Physical Properties for Common Liquid Cryogens**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Boiling Point (BP)@****1atm****(°K)** | **BP****@****1atm****(°C)** | **Liquid-to-Gas Expansion Ratio @ 70F** | **Gas Rel.****Density (Specific Gravity)****@ NTP** | **Critical Temperature (°K)** | **Critical Pressure (Atm)** | **Liquid Density (grams/****liter)** | **Explosive/ Fire Danger**  |
| **Air** | 78.8 | -194.4 |  | 1.0 | -- | -- | -- | No |
| **Argon** | 87.2 | -185.7 | 841 | 1.38 | 150.9 | 48.3 | 1402 | No |
| **Carbon Dioxide** | 194.7 | -78.5a | 790 | 1.52 | 304.2 | 72.8 | 1560 | No |
| **Helium** | 4.2 | -268.9 | 754 | 0.14 | 5.2 | 2.2 | 125 | No |
| **Hydrogen** | 20.3 | -252.9 | 848 | 0.07 | 33.0 | 12.8 | 71 | Yes |
| **Nitrogen** | 77.3 | -195.8 | 696 | 0.97 | 126.3 | 33.5 | 808 | No |
| **Oxygen** | 90.2 | -182.97 | 861 | 1.10 | 154.8 | 50.1 | 1410 | Yes |
| **R-12** | 243.4 | - 29.8 | 294 | 4.17 | 385 | 40.6 | 1487 | No |

**Table Notes**

* BP – Boiling Point
* 1atm – 1 atmosphere standard pressure at 0°C = 101,325 Pascals = 760 torr = 760 mmHg = 29.92”Hg
* NTP – Normal temperature and pressure = 20°C = 68F = 293.15K, and 1 atmosphere = 14.7psia = 29.92”Hg
* Relative Density (Specific Gravity) – The ratio of the density of a listed substance to the density of a standard substance (i.e. air- gas, liquid- water), under standard conditions. For gases in the table, the standard is air at the same temperature and pressure as the substance indicated.
* Liquid to Gas Expansion Ratio given at 70°F and normal atmospheric pressure (1 atm).

a CO2 liquid phase does not exist at 1 atm; CO2 sublimes from solid to gas at -78.5C

* + 1. Liquid Nitrogen – Liquid nitrogen (LN2) is a primary cryogen used at the Penn State University Park campus, as well as other Penn State Commonwealth Campuses. Liquid nitrogen is a colorless, odorless liquid with boiling point of minus 196°Celsius (minus 385°Fahrenheit), density 0.8 kg/liter, and very low viscosity. As the liquid changes to gas at ambient (normal) temperature (~70F) and pressure, the expansion factor of liquid to gas is approximately 696:1. Thus the volume of nitrogen gas generated effectively displaces atmospheric oxygen, and the resulting cold gas is denser than air, accumulates at low levels and expands, thus producing a significant asphyxiation hazard.
		2. Refer to Table 6.1 for physical properties of other cryogenic materials.
	1. Specific Hazards Associated with Cryogenic Materials
		1. Oxygen Deficiency and Asphyxiation - The most significant risk of cryogenic liquids is death by asphyxiation where a spill or leakage depletes the atmospheric oxygen. Nitrogen expands by a factor of approximately 696:1 when changing from liquid to gas at ambient temperature, and can rapidly displace oxygen concentration. Refer to Table 6.1 for expansion ratios of other cryogenic materials.

If the oxygen concentration falls below 18%, adverse effects will occur resulting in loss of mental alertness and performance combined with distortion of judgment. In atmospheres containing less than 10% oxygen, death by asphyxiation is rapid: just two breaths of oxygen-free air kills. Asphyxiation can occur when entering a cryogenic vessel that has been used to store cryogenic liquids if proper ventilation/purging techniques are not employed.

NOTE: *The Occupational Safety and Health Administration (OSHA) has identified an oxygen-deficient atmosphere as a work environment with less than 19.5% oxygen. This level serves as a trigger threshold for alarm activation and evacuation by personnel. Contact EHS for assistance with planning necessary oxygen alarms.*

 **There are no preliminary warnings (symptoms) of oxygen-deficiency, resulting from the introduction of liquefied nitrogen or other cryogens to the atmosphere. Cold, nitrogen-enriched air, is denser than standard air, and may form a blanket which displaces oxygenated air. Asphyxiation is sudden and depending on oxygen concentration may result in unconsciousness, and may be rapidly fatal, if the exposed victim is not rescued and resuscitated.**

If someone is seen unconscious in a cryogenic handling or storage area, and in absence of adequate ventilation, it is likely that they are already dead and there is a serious risk to rescuers of being asphyxiated, unless they are wearing self-contained or air-line-supplied breathing apparatus, and are trained in rescue procedures. In such circumstances, the first actions should be to call the Police Services Dispatch Center, and evacuate the immediate area, opening doors and windows, if safe to do so, on the way out.

*Refer to Appendix A5 – Calculation of Oxygen Depletion Due to Introduction of Liquid Nitrogen and other Cryogens to the Atmosphere.*

6.2.2 Cold Burns, Frostbite and Hypothermia - Contact of the skin with cryogenic liquids (or even cold gas) can cause severe cryogenic burns; the tissue damage that results is similar to that caused by frost bite or thermal burns. While the cold itself can reduce the feeling of pain, the subsequent thawing of tissue can cause intense pain. The eyes are particularly susceptible to permanent damage upon contact with liquid nitrogen.

 Contact with non-insulated parts, equipment or vessels containing cryogenic liquids can produce similar damage. Unprotected parts of the skin may stick to low-temperature surfaces and flesh may be torn upon removal.

 Inhalation of cold vapor can cause damage to the lungs and may trigger an asthma attack in susceptible individuals.

 Hypothermia is a risk due to the low temperatures arising from the proximity of cryogenic liquids. Risk is dependent upon the length of exposure, the atmospheric temperature and the individual; those exposed for prolonged periods should be warmly clothed.

 6.2.3 Oxygen Enrichment - Although not flammable, oxygen when present in higher concentrations can significantly increase the chance of fire or an explosion. The boiling point of oxygen is above those of nitrogen and helium. In closed systems (such as cold traps cooled with liquid nitrogen) these liquids can cause oxygen to condense on their surface (resulting in a bluish liquid on the surface). This can lead to the ignition of normally non-combustible materials, and the flammability limits of flammable gases and vapors being widened. Oil and grease may spontaneously ignite and, as such, should not be used where oxygen enrichment may occur.

 6.2.4 Pressurization and Explosion – Since cryogenic liquids can expand by factors of hundreds, from liquid to gas (refer to Table 5.1), the expansion can cause violent changes in pressure, particularly if this occurs in a confined or enclosed area, subsequently resulting in an explosion.

 Vent systems must be in place to allow gas to escape from work areas. Pressurization can occur due to the following:

* Ice forming on the venting tube, plugging it and preventing gas release.
* Damaged equipment resulting in cryogenic fluids leaking into small areas. Vaporization of the cryogenic liquid vaporizes and causes pressure build up.
* Loss of vacuum inside a cryostat or Dewar.
* If a liquid helium-cooled superconducting magnet "quenches" (changes spontaneously from a superconducting state to a normal state).
* Liquid nitrogen having permeated through sealed cryotubes containing samples which then return to room temperature.
* Direct contact of the cryogenic liquid with water in a tube results in rapid vaporization of the cryogenic liquid and can cause the tube to explode.

 6.2.5 Damage to Equipment - The very cold temperatures of cryogenic liquids can damage equipment and materials, which can result in danger to personnel.

 Examples of damage include the following:

* Spilled liquid nitrogen can crack tiles and damage flooring such as vinyl.
* Rubber tubing may become brittle and crack during use.
* Condensation of water around electrical cables may result in an electrical shock hazard.

6.2.6 Flammable Gas/Explosion - Fire or explosion may result from the expansion of flammable gases such as hydrogen, oxygen, carbon monoxide, or methane, therefore, escaping cryogenic materials (if flammable), can result in a fire or explosion hazard. Hydrogen is extremely flammable and should be treated with extreme caution. Special care shall be taken to alleviate sources of ignition, such as: open flames, exposed electrical/ heating elements, pilot lights or hot surfaces.

 Special precautions should be taken when handling liquid hydrogen and oxygen.

 Closed hydrogen systems should be used to prevent backflow of air. Areas of use should be restricted, clearly marked, and well ventilated. Consult EHS and/or the supplier for pertinent safety precautions. Escaping liquid oxygen, while not a flammable gas by itself, can combine with combustible materials and cause spontaneous combustion. Oxygen clings to clothing and cloth items and presents an acute fire hazard for approximately one-half hour after exposure.

* 1. Material Hazards – The selection of materials calls for consideration of the effects of low temperatures on the properties of those materials. Some materials become brittle at low temperatures. Brittle fracture can occur very rapidly resulting in almost instantaneous failure. Low temperature equipment can also fail due to thermal stresses caused by differential thermal contraction of the materials. Over pressurization of cryogenic equipment can occur due to the phase change from liquid to gas if not vented properly. All cryogenic fluids produce large volumes of gas when they vaporize.
	2. High Pressure Gas Hazards – Potential hazards exist in highly compressed gases because of the stored energy. In cryogenic systems high pressures are obtained by gas compression during refrigeration, by pumping of liquids to high pressures followed by rapid evaporation, and by confinement of cryogenic fluids with subsequent evaporation. If this confined fluid is suddenly released through a rupture or break in a line, a significant thrust may be experienced.
1. **Risk Assessment**

 An initial risk assessment must be performed wherever the potential depletion in atmospheric oxygen concentration would be anticipated to fall below 20.9% (ambient oxygen concentration), considering a worst-case spillage, where cryogenic materials are stored and handled. Where this could result in an oxygen concentration below 18% by volume, corrective actions must be implemented to mitigate the potential. Necessary alarming for local evacuation shall be established where oxygen levels may fall below 19.5%.

A risk assessment will establish the necessary air exchange rate, and provide basis for determining whether current exhaust ventilation is present and adequate to accommodate cryogen leakage conditions, and whether additional controls are needed. Refer to *Appendix A5 for guidance information. Consult EHS for support.*

 7.1 Corrective actions, in addition to oxygen deficiency alarms may include:

* limiting the maximum quantity of cryogenic fluid handled so that oxygen depletion cannot arise,
* moving the operation to a larger room or well-ventilated area,
* providing mechanical ventilation with visual/audible indicators that it is operating.

7.2 Where the risk assessment shows that mechanical ventilation and oxygen alarms are needed, the EHS department must be consulted before any action is taken.

7.3 The Manager/Supervisor or Principal Investigator in coordination with the Facility Coordinator/ Safety Officer, or Campus Designee, is responsible for the development of workplace-specific safety information related to the use and storage of cryogenic liquids.

**8.0 Safe Work Procedures**

 8.1 **Personnel Safety – Personal Protective Equipment (PPE)**

During transfer, pouring, dispensing and normal handling of cryogen liquid, use the following PPE:

* Cryogen-resistant face shield adequate or equivalent to meet ANSI Z87.1 or EN 166,

**Note:** Models with brow guard and chin guard offer the best protection.

* Safety glasses with side shields,
* Loose fitting insulating protective gloves adequate or equivalent to meet EN 511, and splash-resistant apron shall be worn at all times wherever splash risk is high, such as during transport and filling operations,
* Shirt sleeves will be rolled down and buttoned, or an equivalent protection such as a lab coat will be worn in order to prevent liquid to skin contact. Gloves with extra wide open ends (gauntlet-style) are not recommended since liquid may run down/inside the gloves.
* Trousers without cuffs shall be worn, and worn outside boots.
* Closed toe shoes or boots shall be worn.
* Ear protection may be required where excessive noise occurs when filling or venting liquid nitrogen systems. Consult EHS for assistance.

 *Refer to Appendices A1 and A2 for references and guides in safe use and handling of PPE during filling, transfer and transporting of cryogenic materials.*

8.2 **General Safety/ System Design Considerations**

8.2.1 Cryogenic fluids must be handled and stored only in containers and systems specifically designed for these products, and in accordance with applicable standards, procedures, or proven safe practices.

8.2.2 Equipment and systems designed for the storage, transfer, and dispensing of cryogenic fluids shall be constructed of materials compatible with the products being handled and the temperatures encountered.

8.2.3 Fire/smoke detection systems should NOT be installed in immediate proximity to cryogen storage, handling or transfer operations, unless these detectors are designed to differentially detect smoke from a gaseous cryogen vapor cloud. Venting or continuous cloud formation may cause nuisance fire alarm activations. Fire/Smoke detection systems shall be installed as required by the Uniform Construction Code Standards as adopted by the Commonwealth of Pennsylvania.

8.2.4 Cryogen systems, including piping, must be equipped with pressure-relief devices to prevent excessive pressure build-up. Pressure-reliefs must be directed to a safe location. It should be noted that two closed valves in a line form a closed system. The vacuum insulation jacket should also be protected by an over-pressure device if the service is below 77° Kelvin.

 **In the event a pressure-relief device fails, as indicated by a continuous cloud formation (i.e. not just intermittent venting), do not attempt to remove the blockage. Call the Campus or Departmental Safety Officer, or Police Dispatch (863-1111), or Penn State EHS (865-6391) immediately, until assistance is secured.**

8.2.5 If liquid nitrogen or helium traps are used to remove condensable gas impurities from a vacuum system that may be closed off by valves, the condensed gases will be released when the trap warms up. Adequate means for relieving the resultant build-up of pressure must be provided.

8.3 **Cryogen Transfer Operations**

8.3.1 Transfer operations involving open cryogenic containers, such as Dewars, must be conducted slowly to minimize boiling and splashing of the cryogenic fluid. Transfer of cryogenic fluids from open containers must occur below chest level of the person pouring liquid. *Refer to Appendices A1 and A2 for information regarding necessary PPE and procedures.*

8.3.2 Transfer operations shall be conducted only in well-ventilated areas to prevent the possible gas or vapor accumulation, resulting in an oxygen-deficient atmosphere, leading to asphyxiation. The volumetric expansion ratio between liquid and atmospheric nitrogen is approximately 696 to 1. **Refer to Table 6-1 for physical properties and expansion ratios of other cryogens**.

8.4 **Refilling Dewars in Laboratories**

8.4.1 Make sure that there is adequate ventilation. Open the door if you are in a small room (10' x 10').

8.4.2 Remove watches, rings and other metal jewelry on hands and wrists before handling cryogenic liquids.

8.4.3 Wear required PPE as identified at Appendices A1 and A2, as pertinent.

In general, the following types of PPE are required, depending on the type of operations performed:

* Safety glasses
* Cryogen-protective face shield
* Cryogen-protective gloves
* Cryogen-protective apron, or lab coat with buttoned sleeves
* Full length cuffless pants that extend over shoe/boot tops, or foot coverings
* Closed-toed shoes, boots, or foot-protective covers, impervious to liquids, such as leather, and/or suitable for cryogenic liquid contact.
* Hearing protectors may be required when container filling; escaping gas may produce a loud whistle.

8.4.4 Only use Dewars rated for the cryogen being transferred.

8.4.4.1 Never use a Dewar that does not have a pressure relief valve or pressure venting lid or stopper.

8.4.4.2 Use pressure venting lids or stoppers supplied by the Dewar's manufacturer.

8.4.4.3 Never use Dewars with makeshift or homemade lids/stoppers.

8.4.4.4 Glass Dewars must be taped solidly around the outside. The plastic mesh which comes with some small thermos bottles primarily provides some protection for the Dewar, but does not necessarily protect against glass shards resulting from implosion.

8.4.4.5 Dewars larger than 20 Liters must be transported and poured by two people.

8.4.4.6 Never use a funnel during filling, due to the possibility of the cryogenic liquid overfilling and propelling upward.

8.4.4.7 Ensure the receiving vessel is dry.

8.4.4.8 The receiving vessel must be raised so the delivery tube is immediately above the mouth of the vessel (i.e. the cryogenic liquid should never be allowed to fall through air to reach the receiving vessel). Use a table, cart or other mechanical means to position the vessel in the proper location. Never hold the vessel with unprotected hands while filling.

8.4.4.9 To reduce thermal shock, first cool the receiving vessel by dispensing a small amount of cryogenic fluid then, continue the dispensing process. Dispensing should be conducted slowly to minimize splashing, spilling and thermal shock to the receiving vessel.

8.4.4.10 Do not move or bend the fill tube during filling.

8.4.4.11 Stay out of the vapor pathway during dispensing.

8.4.4.12 Do not leave a filling operation unattended.

8.4.4.13 Only use approved materials with cryogens. Unapproved materials (such as plastic, Styrofoam, rubber, wrought iron, hollow tubes, and carbon steel) will become brittle and shatter, or in the case of hollow tubes become over pressurized.

8.4.4.14 Periodically inspect equipment; remove ice and frost blockages from openings to prevent over pressurization.

8.4.4.15 Do not tamper with pressure relief valves. Report any leaks or improperly set relief valves to the manufacturer. It is normal for large Dewars to periodically vent resulting in a loud hissing noise, however if you hear a whistling noise coming from a large Dewar this is an indication that it is empty.

8.4.4.16 Equipment should be kept clean without the use of corrosive cleaning materials that could damage the metal jacket.

8.4.4.17 When manually pouring liquid into a smaller Dewar, ensure that the secondary container is secured, pour slowly to prevent excess splashing, do not overfill, and use a phase separator, if available, to control the vapor path while pouring.

8.5 **Transport of Cryogenic Liquids**

Special precautions must be taken to prevent a spill while transporting cryogens, in addition to minimizing exposures from liquids and vapors. The high liquid to vapor expansion ratio could rapidly displace all oxygen in a room and result in asphyxiation. Implement the following procedures to minimize exposures:

 8.5.1 **Transport within the laboratory or lab building**

* + - Wear all required PPE as pertinent to the size container when transporting liquid nitrogen. Refer to Appendix A1 for small quantity users.
		- Use handcarts equipped with brakes for large Dewars and cylinders.
		- Never transport an open container of a cryogenic liquid.

8.5.1.1 Transport of Large, Pressurized Cylinders

 Pressurized vessels and non-pressurized Dewars are heavy containers and can contribute to material handling injuries. The following aspects must be considered for transport of cryogen vessels:

* Movement of these vessels should be conducted to minimize potential safety hazards to other occupants or pedestrians. A separate person may be used as a hall watch during transfer, as needed.
* Large, heavy cylinders should be transported by personnel who have received training in use of transport dollies and related equipment, as needed for safe transport.
* Use properly-designed transport dollies, carts, or handling equipment, particularly for transport of 20 liter or larger, unpressurized storage containers.
* All transportable Dewar vessels are fitted with wheel and/or undercarriages.
* Assess the route in consideration of:
* rest stops
* movement through populated work areas
* possible obstructions and clutter
* elevators (*refer to procedures below*)
* floor surfaces (level, integral)
* curbs or dikes
* stairs (carefully consider potential for slips and trips which could result in spillages from small hand-held Dewars)
* whether the destination for the gas is ready to accept it

8.5.2 **Transport requiring elevator use:**

PRELIMINARY NOTE: In event of a cryogen container spill within an elevator, the space may quickly undergo oxygen displacement.

8.5.2.1 Pre-label the LN2 container to alert passersby and elevator users that the LN2 cylinder is in transit. *Refer to label guidance at Appendix A4.*

8.5.2.2 Use two persons to conduct the transfer.

8.5.2.3 Safely transport cylinder/container to sending floor, and ensure the necessary transit labels are affixed to the cylinder and sign affixed to elevator door. Dispatch the 2nd party to the sending floor and affix signage to elevator door at the receiving floor.

8.5.2.4 Call the elevator and safely stage the labeled cylinder onto the elevator. Send the elevator to the receiving floor, and move via stairs or separate elevator to the receiving floor.

NOTE: Any potential elevator users at either sending or receiving floors, or by label affixed to cylinder inside elevator, should be warned to not utilize the elevator until the transfer is completed.

8.5.2.5 Once the cylinder has arrived at the receiving floor, receiving party remove cylinder from the elevator and remove the affixed signage from elevator door. Party also remove sign from sending floor, and verify elevator is operational for service.

8.5.3 **Transport outside the laboratory or the laboratory building**

8.5.3.1 Plan the route of transport. Refer to all above precautions for use of elevators, and movement of storage and transport vessels.

8.5.3.2 Always use care when handling equipment. Damage to Dewars could result in the loss of vacuum and increased evaporation. Transport of helium Dewars requires extra care because they are fragile.

8.5.3.3 When at all possible, do not hand-carry cryogenic liquids. For larger Dewars use a stable, wheeled base carrier, designed for the Dewar transport. Check to ensure stability before commencing transport.

8.5.3.4 When carrying a Dewar, make sure it is the only item you are carrying. Hold the Dewar as far away from the face as possible. Be on the lookout for other people who may run into you or bump you.

8.5.3.5 Large mobile Dewars used for transport should be equipped with a braking mechanism. Do not use feet to brake. Steel-toed boots are recommended.

8.5.3.6 Take care to avoid crushing hands or fingers between the vessel or cart and walls or door frames.

8.5.3.7 If there is any risk of tipping, a cart should be used. Wheeled trolleys may not be used if the vessel must pass over elevator thresholds or other slots/crevasses wider than 25% of the wheel width.

8.5.4 **Off-Site Transportation**

Off-site transportation of nitrogen or cryogen Dewars requires special precautions and practices. Contact EHS prior to preparing shipments of cryogen containers. PARTIES MUST CONTACT EHS FOR PROCESSING SHIPMENTS OF LIQUID NITROGEN DRY SHIPPER CONTAINERS. Key requirements for shipment are as follows:

8.5.4.1 All liquid nitrogen must be poured off before packaging and shipping to meet necessary “dry shipper” exception requirements at the USDOT hazardous material regulations (49 CFR 173.320) and IATA Packing Instruction 202. PARTIES MUST CONTACT EHS FOR ASSISTANCE WITH PREPARING LIQUID NITROGEN SHIPMENTS.

8.5.4.2 To meet the exception requirements, for shipment by rail or highway, a liquid nitrogen shipper must not exceed 25.3psig at ambient temperature.

8.5.4.3 Any non-exempt shipments must include emergency contact information. Exempt “dry shippers” do not require emergency contact information.

8.5.4.4 Pursuant to the hazardous material regulations, any person who offers Dangerous Goods for shipment must receive specific training.

8.5.4.5 Parties must contact EHS for preparation of liquid nitrogen Dewar “dry shipper” shipments and for preparation of Bill of Lading.

8.5.5 **Storage of Cryogenic Liquids**

A cryogenic liquid storage unit left open to the atmosphere, or catastrophic failure of a storage unit, could create an oxygen deficient atmosphere. Follow these procedures to reduce the likelihood of this occurrence.

8.5.5.1 Glass Dewars must have an exterior coating/cover to minimize projectiles in the event of an explosion. Newer Dewars may have a plastic mesh over the exterior for this purpose. Older Dewars must be replaced.

8.5.5.2 Only store Dewars in well-ventilated rooms. These rooms should be ventilated at a rate of no less than 6 air changes per hour (ACH); however actual ventilation rate will depend on quantity stored and other factors. Contact the Safety Officer or Safety liaison for assistance by EHS and/or by OPP Engineering Services, if the ventilation rate is unknown.

8.5.5.3 The EHS department may recommend the installation of oxygen detection systems and alarms for cryogenic liquid storage areas depending on location, ventilation, and quantity of material stored.

8.5.5.4 Do not store cryogenic liquids with corrosive or flammable chemicals.

Storage units should be placed so that vents and openings are oriented away from personnel and lab equipment.

8.5.5.5 Bulk cryogenic liquid dispensing areas within buildings must be well ventilated, and also be equipped with continuous oxygen monitoring equipment.

8.5.5.6 Storage of cryogenic liquid Dewars in hallways, unventilated closets, environmental rooms, and stairwells is prohibited.

8.5.5.7 No more than one backup Dewar is allowed per piece of equipment using cryogenic liquids in research labs. Additional Dewars must be stored in areas designed for such storage. Contact the EHS department to evaluate potential storage locations.

8.6 **Preventive Maintenance**

Cryogen storage devices, equipment, ventilation, alarm devices and other equipment shall be maintained according to manufacturer’s recommendations and/or guidelines, and according to a recommended frequency. In the absence of manufacturer recommendations, all such equipment shall be maintained according to industry standards, currently recognized or referenced by Penn State University.

9.0 **Emergency Procedures and First Aid**

9.1 Liquid Nitrogen (LN2) (and other oxygen-depleting Cryogens)

Liquid Nitrogen (LN2) is a commonly used cryogenic liquid. Oxygen depletion resulting from nitrogen gas (or other oxygen-depleting cryogens) may occur rapidly with no warning properties. A person entering an oxygen deficient environment may become disoriented and unable to respond properly. Nitrogen gas (as well as many other commonly used, oxygen-displacing cryogens) are odorless, colorless, tasteless, and inert. The failure of a large Dewar could spill 180 L of LN2, which when expanded to gas will completely displace all oxygen in a 21’ x 21’ x 10’ (4,410 cubic ft.) room. A much smaller spill in the same room could still create a safety hazard. Simply reducing the oxygen content in a room below 19.5 %, will create an oxygen deficient environment, by OSHA definition. Implement the following procedures to minimize the risk of asphyxiation due to oxygen depletion:

9.1.1 If ventilation in the room is less than six air changes per hour (< 6 ACH), or if upon applying the formulae presented at Appendix A5, the oxygen concentration may be reduced below 20%, contact EHS for advice about installing an oxygen level sensor/detection alarm.

9.1.2 Where a low oxygen sensor/alarm is installed, 19.5% should be used as a trigger level for local alarm and local building evacuation, with Police and EHS Contact. A separate low-level alarm of 18.0% should be used to signal building-wide evacuation, followed by Police, Fire, EHS, OPP, and Departmental Dispatch.

 9.1.3 If a spill occurs (<1 liter), immediately evacuate the area. With adequate ventilation, it may be appropriate to return to the area after thirty minutes. For large spills (>1 liter) contact Police Services and EHS immediately as the area may need to be monitored for oxygen levels before it can be determined when it is safe to re-enter.

 9.1.4 If experiencing symptoms such as lightheadedness, dizziness, or confusion, immediately get fresh air and receive medical attention.

 9.1.5 **Where personnel become unconscious in a cryogenic liquid storage area, call Police Dispatch (3-1111), and/or 911 immediately. Victim (may be unconscious) should be removed to a well-ventilated area; however, rescuers should not enter a spill area unless it is considered safe (>19.5% O2) to perform rescue. Self-Contained Breathing Apparatus (SCBA) may be required to perform safe rescue.** **Only properly trained personnel are qualified to use this equipment. Over fifty percent of deaths associated with asphyxiation, particularly in confined spaces, result from rescue attempts by improperly protected rescuers.**

9.1.6 Once victims have been removed to fresh air, the emergency responder will provide rescue breathing or CPR, as needed until paramedics arrive. The person should be kept warm and rested until medical attention can be provided. If breathing has stopped then resuscitation should be commenced by a trained first aid provider. In the event that skin or the eyes come into contact with cryogenic gases or liquid, follow first aid procedures, then immediately seek medical attention.

The following actions should NOT be performed as part of response procedures:

* + use a direct source of heat such as a radiator
	+ permit smoking or alcohol consumption
	+ give analgesics (e.g. acetominophen, aspirin)

For major injuries, apply first aid as far as is practicable and arrange for the victim to receive medical attention.

9.1.7 Where contact has occurred, the focus should be to slowly raise the temperature of the affected area back to normal. For minor injuries, clothing should be loosened and the person made comfortable. Clothing should not be pulled away from burned or frozen skin. The affected area should be doused with copious quantities of tepid water (40°C/105F) for at least 15 minutes and a sterile burn dressing applied to protect any injury until the person can be taken to receive hospital treatment. In the event of clothing contamination with oxygen, hydrogen, or carbon monoxide, it is important to remove clothing, as soon as feasible, evacuate personnel from the facility, and keep personnel away from ignition sources.

 9.1.8 Do not apply dry heat or rub damaged flesh or eyes.

 9.1.9 Employees should notify their supervisor of injuries and complete the First Report of Injury and Illness Form. Contact Work Unit Human Resources for assistance.

10.0 **Spill and Disposal Procedures**

10.1 General Spill Preparedness

When preparing for potential liquid nitrogen or cryogen spills, and particularly during the application of guidance provided at Appendix 1, the following items should be given careful consideration:

* The parties (colleges, departments, work units), and facility locations which may be affected by the spill,
* The availability of building automation systems (BAS) or fire detection systems, as pertinent to alarm installation,
* Possible escape routes,
* The means of isolating the supply of liquid nitrogen, especially if supplied from a bulk tank from the work operations,
* Necessary alarms, alarm levels, and subsequent systems and personnel notifications and responses,
* Emergency support and operational personnel training.

10.1 Minor spill (< 1 liter)

 10.1.1 Evacuate the immediate area. Allow liquid to evaporate, ensuring adequate ventilation.

 10.1.2 Following return to room temperature, inspect area where spillage has occurred.

 10.1.3 If there is any damage to the floors, benches or walls, report it to Facilities and EHS departments.

 10.1.4 If any equipment has been damaged following the spillage, inform the supervisor of the area.

10.2 Major release (> 1 liter)

 10.2.1 Shut off all sources of ignition.

 10.2.2 Evacuate area of all personnel.

 10.2.3 Inform EHS department and the supervisor of the area.

 10.2.4 DO NOT return to the area until it has been declared safe by EHS department.

10.3 Disposal Considerations

10.3.1 Care needs to be taken when disposing of cryogenic liquids.

 10.3.2 DO NOT pour cryogenic liquids down the sink - they will crack waste pipes causing potentially dangerous leaks.

 10.3.3 DO NOT store cryogenic substances or allow them to vaporize in enclosed areas, including: fridges, cold rooms, sealed rooms and basements.

 10.3.4 Cylinders with leaking valves should be moved to outdoor areas for cryogen evaporation, IF movement can be safely conducted. Portable oxygen monitoring should be conducted to evaluate safe conditions.

 10.3.5 Large cryogen cylinders should be returned to supplier for safe disposal.

11.0 **Information & Training Requirements**

11.1 Training should be given in all aspects of the use and handling of cryogenic materials. A combination of on the job skills, instructions and information covering the following topical areas provides a minimum standard to which all users should be trained:

* Understanding of the Safety Data Sheet (SDS), the risks involved and where to obtain information
* Understanding the risks and effects of oxygen depleted atmospheres
* Conducting a risk assessment
* Use of PPE
* Handling cryogenic materials
* Moving containers of cryogenic materials (>1 liter)
* Emergency procedures
* Spillage procedures, and if necessary
* Manual handling of larger storage vessels
* Dispensing bulk quantities (> 1 liter)

11.2 OSHA Hazard Communication Requirements

 The OSHA Hazard Communication Standard (HCS) found at Title 29 Code of Federal Regulations (CFR) Part 1910.1200, is established to ensure that the hazards of all chemicals produced or imported are evaluated and that information concerning their hazards is transmitted to employers and employees. The responsible work unit must ensure the pertinent Safety Data Sheets (SDS), as prepared to meet current OSHA requirements are readily accessible to users and emergency responders. These SDS requirements include the OSHA format and content changes reflecting adoption of certain Globally-Harmonized System (GHS) requirements.

11.3 Training Proficiency – Personnel performing cryogen handling, transfer, and filling operations must receive necessary training and supervisory oversight to ensure these operations with cryogens can be performed safely.

11.4 Training Documentation – Training records must include the nature of the training, content, the date and length in hours, instructor(s), participants, and pertinent verification.

11.5 Training Frequency – Training shall be conducted prior to working with cryogenic materials, and as necessary for personnel to retain proficiency. Typically, this involves some form of annual or periodic refresher of key information and practices.

12.0 **Records**

12.1 All risk assessment records, training records, installation and equipment maintenance records shall be maintained on file by the responsible work unit, and be made readily available to EHS, or other EHS-approved designees, upon request.

Records shall be maintained according to current Penn State and departmental requirements.

13.0 **Revision History**

|  |  |  |  |
| --- | --- | --- | --- |
| **Revision No.** | **Document/ Change Summary** | **Revision****Date** | **Revision Originator** |
| EHS-000015-00  | Initial SOP document  | 10/14/2016 | THD |
| EHS-000015-01 | Update format; update contents to reflect distribution as a guidance document vs. a policy document. | 05/01/2017 | THD |
| EHS-000015-02 | Update document and Appendix A5 with references to Table 6.1 for other cryogens. | 3/04/2022 | THD |

**Appendices**

**A1 – Penn State Laboratory Research & Safety Plan/ Liquid Nitrogen Handling Fact Sheet**

**A2 – Protective Clothing & Equipment for Use with Cryogens**

**A3 – Emergency Procedures & First Aid**

**A4 – Labeling of Cryogen Containers**

**A5 – Calculation of Oxygen Depletion Due to Introduction of Liquid Nitrogen to the Atmosphere**

**Appendix A1 – Penn State Laboratory Research & Safety Plan/ Liquid Nitrogen Handling Fact Sheet**

**- Document found on subsequent page -**

**Liquid Nitrogen (LN2) Handling Fact Sheet**

For small-quantity and -volume users who do tasks such as grinding samples, snap freezing cells, or filling small Dewars

Cryogens such as liquid nitrogen can be hazardous to laboratory workers if not handled properly. Depending on the situation, improperly handled liquid nitrogen can lead to oxygen deficiency, cold burns, and explosions.

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**General precautions when working with liquid nitrogen:**

* Liquid nitrogen splashes can result in cold burns. Personal Protective Equipment (PPE) requirements are designed to avoid eye and skin contact.
* Never handle liquid nitrogen, or items that have been in liquid nitrogen, with bare hands.
* Use cryogenic gloves that are designed specifically for working with liquid nitrogen.
* Do not use or store liquid nitrogen in confined areas, walk-in refrigerators, environmental chambers, or rooms without ventilation. A leak in such an area could cause an oxygen-deficient atmosphere.
* Never store liquid nitrogen in a sealed, airtight container at a temperature above its boiling point (-195.8°C). The pressure resulting from the production of gas may lead to an explosion.

**Wear the following personal protective equipment (PPE) when working with liquid nitrogen:**

* **Chemical splash** goggles should be worn. A **full face** shield may also be appropriate if splashes are anticipated.
* Hands must be protected with **thermal insulated gloves** (e.g. cryo gloves) that can quickly be removed if liquid nitrogen is spilled on them. Even with insulated gloves, hands should not be submersed into liquid nitrogen.
* Protect the rest of the body with **long pants, lab coat**, and **closed toe shoes**. If wearing boots, it is recommended that pants cover the boots rather than be tucked into them (to avoid liquid nitrogen spilling into the boots).

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**In case of exposure to liquid nitrogen:**

* Remove any clothing that is not frozen to the skin. Do NOT rub frozen body parts because tissue damage may result.
* Place the affected body part in a warm water bath (below 40°C). Never use dry heat.
* Obtain medical assistance as soon as possible.

Working with larger quantities of liquid nitrogen can pose additional hazards. Please contact EHS for further guidance if you do tasks such as filling larger Dewars or charging NMR or MRI systems. EHS can assist in assessing the risk of oxygen depletion that may be associated with these tasks.

**Appendix A2 – Protective Clothing & Equipment for Use with Cryogens**

Eye protection: As a minimum, safety spectacles with side shields must be worn whenever handling liquid nitrogen. A face shield compliant to ANSI Z87.1 must be worn where there is a risk of splashing the face or eyes, e.g. during filling operations. Models with brow guard and chin guard offer the best protection.

Hand protection: For filling operations, non-absorbent, insulated gloves compliant to ANSI Z87.1, or loose fitting leather gloves (for ease of removal in case of spillage) must be worn. Gauntlet style gloves are not recommended as liquid may run down inside them. These gloves will also protect the skin from contact with objects that have been cooled by liquid nitrogen. **Gloves are not intended to protect the hands against immersion in liquid nitrogen.**

Foot protection: Closed toe shoes or boots shall be worn when working with cryogenic materials. When transporting large cylinders, i.e. > 20L, utilize steel toe shoes or boots. Open toed shoes shall not be worn.

Clothing: As a minimum, a lab coat or overall should be worn. If boots are worn then trousers should be worn outside of them, not tucked into them. A splash resistant apron will give added protection where Dewars are being lifted or carried, or wherever there is a high risk of splashing, e.g. during filling operations.

Ear protection: Ear plugs or ear defenders may be required where excessive noise occurs when filling or venting liquid nitrogen systems (a noise assessment may be needed.

**DETAILED PERSONAL PROTECTIVE EQUIPMENT GUIDANCE**

**Refer also to the subsequent PPE decision matrix.**

Please refer also to the **Liquid Nitrogen Handling Fact Sheet (Appendix A1)** for further details related to small quantity handling, such as for grinding samples, “snap-freezing” cells, filling small dewars, or handling very small quantities of liquid Nitrogen.

*Refer to the Penn State Personal Protective Equipment Program, for further details on proper selection and use of personal protective equipment (PPE), and for cryogen-related PPE*.

Appendix A2 Reference

1. U.S. DOL/ Occupational Safety and Health Administration – OSHA QuickFacts sheet -

 <https://www.osha.gov/Publications/laboratory/OSHAquickfacts-lab-safety-cryogens-dryice.pdf>

**PPE Decision Matrix**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Operation** | **Potential Hazard** | **Face Shield and Safety Glasses (with Side Shields)** | **Safety Glasses (with Side Shields)** | **Cryogen Gloves**  | **Closed-Toe Shoes** | **Long Pants (No Cuffs)** | **Lab Coat or Long-Sleeve Shirt** | **Remarks** |
| Pouring small non-pressurized (<5 liters) volume of LN2 between open containers | Eye or skin injury from splashing |   | X | Recommended1 | X | X |  Recommended1 | Avoid pouring cryogens from above chest level |
| Work with experimental samples immersed in LN2 in small (~1 L) dewar | Frostbite and burns from cold surface contact |  | X | Recommended1 | X | X | Recommended1 | Thermally insulated hand tools may be an effective alternative to gloves |
| Handling chilled metal transfer lines | Frostbite and burns from cold surface contact |  | X | X | X | X |  X |  |
| Dispensing LN2 from a pressurized line to an open dewar2 | Frostbite and burns from cold surface contact, eye and skin injury from splashing |  X | X | X | X | X |  X |  |
|  Closed pressurized line LN2 or LHe transfer | Frostbite and burns from contact with the unexpected release of pressurized cryogen liquid or gas |  X | X | X | X | X |  X |  |

1 Recommended. For a few limited operations, cryogen gloves or long-sleeve shirts/lab coats may not be needed.
2 When using a phase separator between the pressurized LN2 line and the open non-pressurized dewar, the risk of a cryogen splash is substantially reduced.

**Table Reference**: *Table D-2. Summary of PPE Requirements for Cryogen Use*; Chapter 29 – Safe Handling Practices for Cryogenics; Lawrence Berkeley Laboratory, ES&H Manual.

**Appendix A3 – Emergency Procedures & First Aid**

(a) **Emergency procedures**

Refer to Appendix A5 to estimate/assess oxygen depletion within a room, based on the effects of a liquid nitrogen or other cryogen spill. The results of the calculations may identify a need for evacuation, where spillage above a certain volume occurs. If the risk assessment identifies this condition, alarm levels and corresponding actions must be identified. OSHA defines an oxygen level of 19.5% as oxygen-deficient. No occupancy or entry should be permitted below this level, except by trained and properly protected emergency responders. This level should be used for local evacuation. Self-contained breathing apparatus (SCBA) respirators are required for entry to environments that are oxygen-deficient. As oxygen levels decrease, health impact and subject impairment of ability to self-rescue increases. Necessary actions, responses, and procedures should accompany each pertinent alarm limit/level, following a spill incident. Planning should consider:

* + Personnel, departments affected by the spill;
	+ Sensor/alarm requirements, system response with respect to building automation and life safety,
	+ Planned escape routes;
	+ Ventilation, and other integral failsafe or engineering devices to isolate the LN2 or cryogen supply, particularly with respect to a bulk storage tank, or portable storage Dewars;
	+ Evacuation and return-to-occupancy procedures, and means to prevent access until oxygen levels return to normal;
	+ The anticipated pathways for LN2 or other cryogen impact (i.e. penetrating floors, accumulating in ducts, or other areas);
	+ Responder procedures to safely enter to perform rescue (i.e. fire responders must observe safe limitations for entry to an operating super magnet work area);
	+ Procedures for communication during and following an incident.

Emergency procedures should specify actions (what to do and not to do) in event someone has collapsed in an area due to low oxygen concentration. Rescue attempts by poorly equipped and poorly trained rescuers may result in additional fatalities. Rescue should not be attempted without proper training and equipment. The necessity for proper engineering controls to restrict asphyxiant gas supply, and/or to ventilate areas rapidly, without requiring entry, cannot be overemphasized. Properly oriented fire service or hazmat personnel are likely to be the only suitable responders in these situations.

 (b) **First aid - inhalation of oxygen-deficient atmospheres**

Remove conscious victims to fresh air and keep them warm. First Aid/CPR and or emergency medical responders must determine need for medical attention, and act promptly. If the victim is not breathing, basic first aid/CPR must be initiated, emergency medical support summoned.

(c) **First aid - cold burns and frostbite**

Flush the affected skin with copious amounts of room temperature or luke warm water, or place the affected part in lukewarm water, and do not apply any form of direct heat. If possible, move the victim to a warm room. First aid/CPR-trained personnel must assess and/or summon medical assistance to address cold burns and associated tissue damage.

(d) **First aid – liquid nitrogen splash in the eye**

Flush eyes with running water for at least 15 minutes and summon medical attention as quickly as possible.

**Appendix A4 – Labeling of Cryogen Containers**

Liquid nitrogen Dewars must be clearly and adequately labelled. As a minimum, the label must include:

* Product Designation or DOT Shipping Name: **Nitrogen, Refrigerated Liquid**
	+ Product Identification Number (“UN” Number): **UN 1077**
	+ Product Sign – Shipping Label:

(green diamond containing cylinder symbol, Number 2 at bottom)

The label should be at least 100mm high, unless the size and/or shape of the Dewar make this

impractical. In this case the label should be as large as possible.

Safety Signs may include:





Globally-Harmonized OSHA HMIS OSHA PPE requirements sign

Symbol for Cryogenic Material



Example PPE Requirements – Filling operations

**Appendix A5 – Calculation of Oxygen Depletion Due to Introduction of Liquid Nitrogen, and other Cryogens to the Atmosphere**

**The following scenarios are provided as guidance in determining whether adequate ventilation is present for a planned storage of liquid nitrogen and other cryogens**. **Refer to Table 6-1 for expansion ratios for other cryogens.**  For actual planning, please contact EHS for assistance. Certain data and information, such as current or planned air exchange rates, may be secured by the assigned OPP Project Manager (Design & Construction Services), or the dedicated Building Engineer (Engineering Services).

Four oxygen depletion scenarios are subsequently presented. Each scenario represents a different type and magnitude of liquid nitrogen (LN2) release.

1. **Normal evaporative loss from a LN2 container**
2. **Dewar or LN2 container filling loss**
3. **LN2 Vessel - spillage of contents**
4. **Loss of the entire contents of an LN2 vessel, immediately after filling**

The Compressed Gas Association (CGA), British Compressed Gases Association (BCGA), and other commercial organizations recommend that a “risk assessment” be conducted to determine oxygen depletion due to liquid nitrogen release, under worst-case conditions. Scenario 4 above represents worst-case conditions. Consult Penn State EHS (814) 865-6391 for assistance in performing a risk assessment, and for support in determining necessary ventilation for LN2 installations.

**Oxygen Depletion Formula**

The oxygen concentration, **Coxygen** following depletion in a room due to liquid nitrogen leakage or introduction, may be calculated using the formula:

**Coxygen = 100 x Voxygen / Vroom , where:**

**Voxygen = calculated as in 2), 3), or 4) below, and**

**Vroom = the room volume in cubic meters (m3).**

 **Note: 1 cubic foot (1f3) = 0.028 m3**

**Scenario 1 – Normal evaporative losses**

Over a long enough period, the percentage decrease in oxygen concentration due to normal

evaporative losses from a liquefied nitrogen or other cryogen Dewar or vessel may be estimated by:

|  |  |  |
| --- | --- | --- |
| **Gas loss ( m3 )**  | **x ( 1 )** | **x ( hour )** |
|  **(hour)** |  **(Vroom m3 )** |  **(Nair changes)** |

 **% Oxygen depletion = 0.21 x Ct (100) where:**

 **Ctcryogen =**

* 0.21 = normal concentration of oxygen in air (or 21%)
* Ct = relative increase nitrogen or other gas concentration
* 100 = multiplier to obtain gas concentration %
* L = the gas evaporation rate in m3 per hour (m3 h-1)
* N = the number air changes per hour (ACH)

Calculating estimated losses (L) of liquid nitrogen (or other cryogens), due to evaporative losses:

Manufacturers provide evaporation loss values for their vessels (normally as a volume of liquid nitrogen lost per day). As a safety factor, these losses should be estimated by doubling the figures, to accommodate the deterioration of insulation performance over the lifetime of the vessel.

**Loss due to evaporative losses in m3 h-1 = (2) x (696Lgas) x (L liq loss Mfr) x (Day) x (1 m3) where:**

 **(1L liq) (Day) (24hrs) (1000Lgas)**

|  |  |  |
| --- | --- | --- |
|  | 2 | doubling (safety) factor that accommodates the deterioration of insulation |
|  | 696 | **expansion factor for converting liquid nitrogen to gas (1 liter LN2 produces 696 liters gas at 70F). Use appropriate expansion factors (Table 6.1) for other cryogens:** Liquid Helium - 754, Liquid Argon - 841, Liquid CO2 - 790 |
|  | 24 | 24 hours (= 1 day) LN2 loss |
|  | 1,000 | conversion factor: 1,000 liters gas = 1 cubic meter gas |

Example 1 – Manufacturer’s normal evaporative loss – LN2

Basement Room dimensions: 13 ft x 10 ft x 10 ft = 1300 f3 OR 36.4 m3

LN2 containers: Five (5) x 10 liter Dewars

Mfr’s evaporative loss value: 0.15 liters LN2 per day, per Dewar

Air change rate: 0.4 air changes per hour (ACH)

**Loss** **= (2) x (696) x [(5) (0.15)] ÷ (24 x 1000) = 0.044 m3 h-1**

**Ct** = **L ÷ (Vroom m3) x N = 0.044 ÷ (36.4) x (0.4) = 0.003 relative increased N2**

**Therefore, % O2 depletion in air = 0.21 x Ct x 100**

 **0.21 x 0.003 (100) =** **0.06%**

**In this case, the normal evaporation losses have a relatively insignificant effect on the oxygen content of the room. However, where Ct = 0.07 or higher, then the oxygen depletion becomes 1.5% or more, and extra ventilation and/or oxygen monitoring will be required.**

**Scenario 2 – LN2 Container Filling Loss**

When a vessel is filled, some loss always occurs as it is cooled to liquid nitrogen temperature. According to the BCGA, it is recommended that a loss of 10% of the vessel’s capacity be assumed in order to assess the risk from LN2 losses during container filling.

**Voxygen (m3) = 0.21 [Vroom − (0.1 x Vvessel x 696 x 10-3)] where:**

* **Voxygen** = represents volume oxygen in room following losses
* 0.21 represents the normal concentration of oxygen in air (21%)
* 0.1 represents the loss of 10% of the vessel’s capacity
* **Vvessel**  = vessel’s capacity in liters
* 696 = gas expansion factor for N2 (1 liter LN2 produces 696 liters N2 gas)

**Use appropriate expansion factors for other cryogens:**

Liq. Helium - 754, Liq. Argon - 841, Liq. CO2 - 790

* 10-3 = factor to convert liters air to cubic meters air (1000 liters = 1 m3)

Example 2 – LN2 Container Filling Loss

Use same room dimensions and Dewar quantities identified in Example 1, as noted above (10L Dewar, 36.4 m3 room volume):

**Voxygen (m3) = 0.21 [36.4 − (0.1 x 10 x 696 x 10-3)] = 7.49 m3**

**Room O2 conc. or Coxygen = 100 x Voxygen / Vroom = 20.6%**

**In this scenario, vessel filling losses do not significantly impact room oxygen concentration in normal use.**

**Scenario 3 – LN2 Vessel – Spillage of Contents**

Use same room dimensions and Dewar quantities identified in Examples above:

(10L Dewar, 36.4m3 room volume)

**Use appropriate expansion factors for other cryogens:** Liq. Helium - 754, Liq. Argon - 841, Liq. CO2 - 790

Example 3 – Spillage of Entire Vessel Contents:

**Voxygen (m3) = 0.21 [Vroom − (Vvessel  x 696 x 10-3)]**

**Voxygen = 0.21 [36 − (10 x 696 x 10-3)] = 6.09 m3, and**

**Coxygen = 100 x Voxygen ÷ Vroom = 16.7 %**

**Thus, in this example, the spillage would significantly deplete the oxygen concentration.**

**Scenario 4 – Loss of Entire LN2 Vessel Contents after Filling**

**This example represents the worst case that should be considered in the risk assessment, i.e. oxygen depletion by both vessel filling and spillage of entire contents are taken into account.**

Example 4 – Vessel filling losses (LN2), followed by spillage of entire contents

Use same room dimensions and Dewar quantities identified in Examples above:

(10L Dewar, 36.4m3 room volume) and assume 10% losses due to filling.

**Use appropriate expansion factors for other cryogens:** Liq. Helium - 754, Liq. Argon - 841, Liq. CO2 - 790

**Voxygen (m3) = 0.21 [Vroom − (1.1 x Vvessel x 696 x 10-3)]**

**where:** 1.1 = 110% or 10% filling loss + 100% loss of the vessel’s contents by spillage

**Voxygen (m3) = 0.21 [36 − (1.1 x 10 x 696 x 10-3)] = 5.95 m3**

**Coxygen = 100 x Voxygen ÷ Vroom = 16.5 %**

**This risk assessment demonstrates that alternative storage arrangements must be considered, room ventilation increased, and/or oxygen monitoring must be installed. Alternative arrangements may include:**

* siting the vessels elsewhere
* using smaller or fewer vessels
* arranging for any pressure relief devices to vent to a safe place outside of the room
* installing mechanical ventilation, possibly linked to the low oxygen alarm
* installing flow fault alarm, to warn occupants and/or to signal control actions through the Building Automation System (BAS)
* require staff to wear personal oxygen monitors

**Appendix A5 Reference:**

Compressed Gas Association – Publication 12 (P-12) – Safe Handling of Cryogenic Liquids, edition 5 (2009).

**Appendix A6 – General References**

1. **Linde Product Safety Information – Liquid Nitrogen**

<http://www.lindepremiumproducts.com/internet.lg.lsg.usa/en/images/psa_liquid_nitrogen892_21856.pdf>

1. **Airgas Safety Data Sheet – Liquid Nitrogen**

<https://www.airgas.com/msds/001188.pdf>

1. **Lawrence Berkeley National Lab – Online cryogen handling course** [http://www2.lbl.gov/ehs/training/webcourses/EHS0170/#](http://www2.lbl.gov/ehs/training/webcourses/EHS0170/)
2. **Occupational Safety and Health Guideline for Nitrogen**. U.S. Department of Labor OSHA. <http://www.osha.gov/SLTC/healthguidelines/nitrogen/recognition.html>
3. **Lawrence Berkeley Laboratory Quick Start Guide – Chapter 29: Safe Handling Cryogenic Liquids**

<http://www2.lbl.gov/ehs/pub3000/CH29/CH29.html>

**Associations with Resource Information**

**Compressed Gas Association**
14501 George Carter Way, Suite 103
Chantilly, VA 20151
Phone: 703-788-2700
cga@cganet.com

**National Institute of Standards and Technology**
100 Bureau Drive
Stop 1070
Gaithersburg, MD 20899-1070
Phone: 301-975-6478
inquiries@nist.gov

**National Fire Protection Association**
1 Batterymarch Park
P.O. Box 9101
Quincy, MA 02269-9101
Phone: 800-344-3555
[www.nfpa.org](http://www.nfpa.org)