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Spallation Safety

Neutron Never

Source Stops

Cryogenic Safety Manual

January 2004

Many work areas at the Spallation Neutron Source are used to store and use compressed or liquefied gases. These gases present a number of unusual hazards not encountered in everyday life. One such hazard results from uncontrolled venting, leading to a reduction in ambient oxygen. If oxygen levels drop significantly, unconsciousness or death could occur rapidly with little warning. The large quantities of gases available at SNS are sufficient to impact areas well away from the release point.

This booklet explains (1) the types of cryogenic hazards you might encounter, (2) how to recognize and protect yourself from these hazards, and (3) what you must do to avoid creating cryogenic hazards for yourself and others.

The SNS *Cryogenic Safety Policy and Procedure* serves as a companion to this booklet and should be consulted for more detailed information. If after reading this booklet, you don't feel that you have enough information to enable you to work safely in a cryogenic area, contact your supervisor, safety representative, or an experienced SNS cryogenic worker with your questions, concerns, or recommendations for improved safety operation.

Worker Requirements for Entry into Cryogenic Areas

Personnel who enter cryogenic areas without a qualified escort must inform the ASD safety officer 1) that this pamphlet has been read and understood, 2) obtained clarification for parts/requirements not understood, and 3) believe themselves knowledgeable in the operation of SNS's cryogenic safety alerting systems. Other methods of demonstrating knowledge of cryogenic safety at a level appropriate to the anticipated work that are acceptable to the ASD safety officer will also meet the intent of cryogenic safety training.

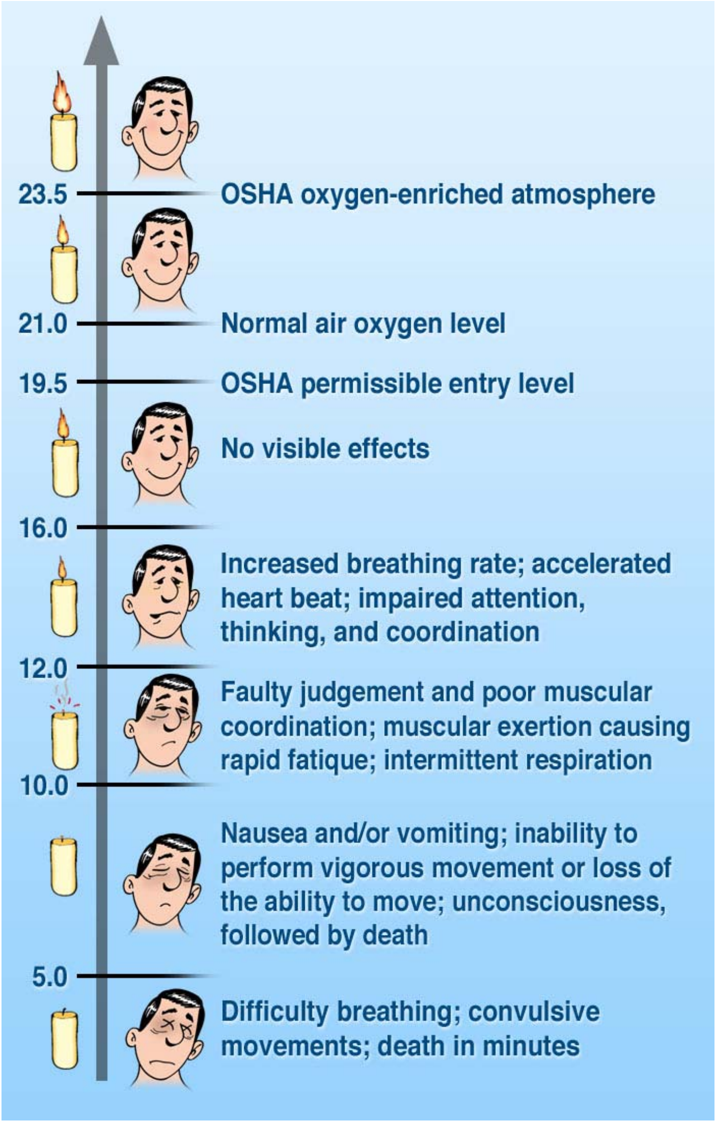
Visitor Requirements

Visitors who do not meet the worker requirements must be accompanied by a qualified escort.

Requirements for Tours

Tours should be considered as jobs. A Job Safety Analysis (JSA) (which includes determining the number of qualified escorts needed) must be completed. Safety information must be provided to all tour members before the start of the tour.

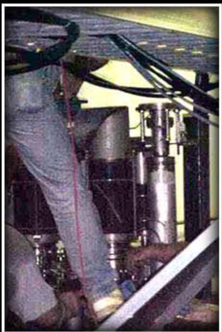
The general effects of changes in oxygen concentrations aren't immediately visible except in the extremes of the range presented below.



TO PREVENT CRYOGENIC INJURIES

YOU MUST

be able to recognize potential hazards and determine the protective measures necessary to minimize risk.



Difficult footing

Moving heavy objects

Touching cold surfaces

Cryogenic fluid release:

exit the release area while avoiding the vapor cloud.

Properties of Some Cryogenic and Other Fluids

Fluid	Odor	Color	T_{NBP}(°K)	MP (°K)	Exp Ratio	SG	)$H_{<}$(kJ/kg)
Helium	none	clear	4.2	na	754:1	.14	20
Hydrogen	none	clear	20.3	13.6	860:1	.07	446
Nitrogen	none	clear	77.3	63	696	.97	199
Air	none	clear	78.8	57	728	1.00	205
Argon	none	clear	87.3	83.6	842:1	1.38	242
Oxygen	none	clear	90.2	54.7	860:1	1.10	255

Substance with higher BP condenses first upon cooling

Substance with lower BP vaporizes first upon warming

Lighter than air

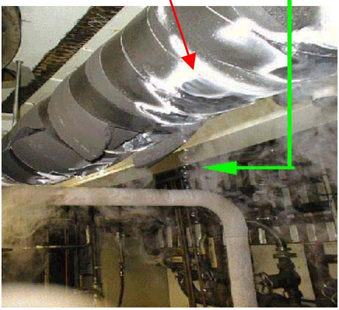
Heavier than air

Both situations foster concentration of oxygen in the condensate

Substance with lower MP melts first. Oxygen concentrated in liquid runoff

Takes the least amount of heat influx to vaporize

All undergo many volume expansions from liquid to gaseous state



Some cryogens are toxic, combustible, highly reactive, and even explosive. Carbon monoxide is both toxic and combustible; fluorine is toxic and highly reactive; ozone is toxic, highly reactive, and explosive in concentrated form.

Cryogenic hazards

Cryogenic burns / frostbite hazards

Direct contact with cryogenic fluids or cold equipment can cause nearly instantaneous serious damage to living tissue, similar to that caused by thermal burns. Prolonged contact or rapid flow to either liquid or cold gas for more than a second or two can also freeze exposed tissue. The eyes are especially sensitive to cold damage.

To control hazards,

DON'T:

- **Overfill containers or carry more than one container.**
- **Use gloves with gauntlets or wear pants with cuffs that could pool and channel spills.**
- **Make bare skin contact with cryogenic liquids, uninsulated pipes, or equipment.**
- **Work on charged cryogenic equipment without protective equipment.**

DO:

- **Use tongs or cryogenic gloves to handle charged liquid containers or other objects that might be cold.**
- **Stay out of the path of boiloff gases.**
- **Pour cryogens slowly to minimize boiling and splashing.**
- **Use a phase separator or special filling funnel when transferring cryogens.**
- **Ensure that all pressure relief valves and rupture disk vent paths are directed away from personnel.**
- **Perform routine inspections of all safety equipment and cryogenic systems.**
- **Maintain all cryogenic equipment.**

Oxygen Deficiency/Asphyxiation Hazards

Most cryogenic fluids are chemically inert and therefore not toxic. However, the extreme volume expansion from a liquid to a gas when warmed can reduce the amount of oxygen in the air. Gases lighter than air like helium and hydrogen are expected to rise because of their buoyancy. Gases heavier than air like argon and neon are expected to remain near the floor. Caution should be used when making these assumptions because the type and size of the release and the environment into which the release occurs could exert a large influence on subsequent mixing and dispersion.

Normal Oxygen Atmosphere

GAS	VOLUME
Nitrogen	78%
Oxygen	21%
Argon +	1%

Health Effects of Reduced Oxygen

Percentage of oxygen in the air (%)	Symptoms (effects noted below are time dependent)
21-19	None
>19-15	Reduced reaction times
>15-12	Heavy breathing, rapid pulse, lack of coordination
>12-10	Dizziness, unclear thinking, lips slightly bluish
>10-8	Nausea, vomiting, loss of consciousness
>8-6	Death within 8 minutes, brain damage within 4-8 min
4	Coma within 40 seconds, respiratory failure, death

Sudden asphyxiation is known to occur from inhalation of pure inert gases or air with little oxygen (<5%). Unconsciousness can be immediate, and a person will fall as if struck down. If not moved to fresh air, the person could die in a few minutes.

You Must Remember This:

DO NOT enter or occupy an area in which the oxygen is less than 19.5% without taking precautionary measures.

To control or minimize asphyxiation hazards, consider:

- Oxygen monitoring in the area or on the person.
- Currency of calibration of monitoring equipment.
- Evacuation routes away from the release area.
- Immediate evacuation in the event of an alarm.
- No entry into areas/rooms that are alarming.
- Use of natural or local exhaust ventilation.
- Amount of cryogen with respect to volume of containing spaces in transporting, storage, and use.
- Provision of surveillance by another person.

You Must Remember This:

An oxygen deficiency alarm (light or horn) means to evacuate immediately and in a direction away from signs or sounds of a release.

Hazards Caused by Condensation of Air

All cryogens can condense substances that boil at higher temperatures. All other substances are solids at the temperature of liquid helium. Condensation of air on cold surfaces is a special concern because the oxygen content of the condensate is enriched. In the presence of oxygen-enriched atmospheres, some noncombustible substances can burn, combustible substances normally burn more vigorously, and some substances react so vigorously they generate explosive forces. Contact of air with liquid nitrogen leads to the contamination of the liquid nitrogen. If this contaminated liquid is subjected to nuclear radiation, ozonides and nitrogen oxides can form. These contaminants are explosive upon warming to room temperature.

- If condensation is internal to a cryogenic system, a mechanical hazard could result from the plugging of pressure relief ports or erosion of valve seats.

• Internally deposited condensate upon warming can cause over-pressurization.

• Condensate dripping onto other equipment can cause embrittlement.

• Normal air in contact with surfaces below about 90 K will form oxygen-enriched condensate (about 50% oxygen). The subsequent evaporation of the condensate can result in oxygen enrichment of the ambient environment.

Pressure Buildup Hazards

Recall the large volumes produced when liquid cryogens are warmed to the gaseous state. If warming takes place in an enclosed vessel, pressure builds unless the gas can be vented. Without venting, pressure increases till the liquid density at ambient temperature is reached or the vessel ruptures.

To prevent pressure buildup:

• Provide pressure relief devices where cryogenic liquids are enclosed, including all delivery lines and cutoff valves.

• Size pressure relief devices for the maximum possible back-pressure under all operating conditions.

• Inspect all pressure-relief devices at regular intervals for leakage, frosting, and dirt accumulation.

Embrittlement Hazards

Typically, materials increase in strength as their temperature is lowered. However, some metals loose ductility and can break suddenly under normal stress conditions. There are two ways in which structural materials can become brittle in cryogenic service: low-temperature embrittlement and hydrogen embrittlement.

To prevent embrittlement:

• Use containers, equipment, and replacement parts specifically designated for cryogenic service.

• Use methods of joining materials that ensure the desired performance is preserved.

Thermal Stress Hazards

Usually the change from ambient temperature to cryogenic temperature will cause substantial thermal contraction. If system design does not accommodate this contraction, large thermal stresses can result.

To minimize the potential for thermal stress failures:

- Use only cryogen-approved containment devices.
- Select materials and equipment that can accommodate the effects of thermal stress.
- When starting up and shutting down a system, allow for gradual cooling/warming.

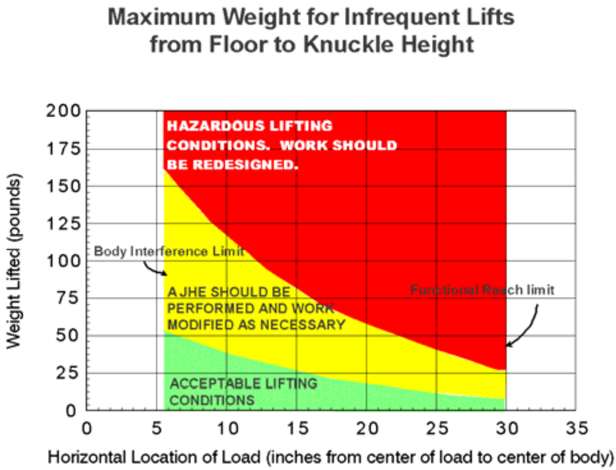
Materials Handling Hazards

This relates to the movement and handling of portable systems.

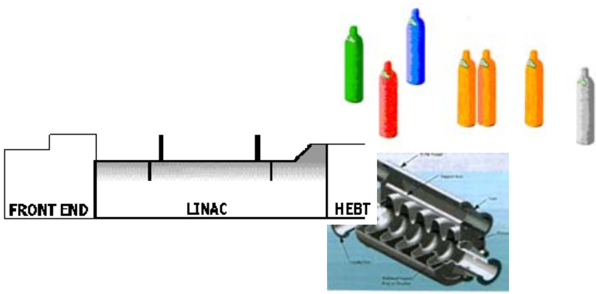
To minimize physical hazards and ergonomic stresses:

- Use dewars with wheels
- Ensure wheeled dewars are equipped with a breaking mechanism
- Take care to avoid crushing hands or fingers between the vessel and walls or doorframes when moving containers
- Use two persons when moving large wheeled vessels.
- Make sure there is a smooth and otherwise unobstructed path of travel before moving cryogenic vessels.
- Use the smallest containers suitable for the task at hand, particularly when dewars must be lifted and held in awkward positions to fill other systems.
- Consider using mechanical lifting devices or redesigning the work for any lifting that exceeds acceptable lifting conditions depicted in the graph on the next page.

Materials-Handling Hazards



Where cryogens are used at SNS



A variety of cryogens are used in standard industrial and laboratory operations throughout the complex. For the most part, they are used in small quantities, and although hazards exist, the risks associated with them are proportionately smaller and are dealt with using standard practice.

There are some areas where substantial amounts of cryogenic fluids are used. Because of the large quantities available, their inadvertent and uncontrolled release could produce an oxygen-deficient environment. These areas are referred to as **CRYOGENIC AREAS** and **have special operational safety requirements and systems**. At this time there are two such designated areas at SNS: (1) the super conducting section of the linac and (2) the central helium liquefier, including the control room and warm compressor area.

ACCESS

Work in and general access to these areas is restricted to personnel who have received cryogenic hazard recognition training or who are supervised by trained personnel.

MORE ON HAZARD RECOGNITION AND REQUIRED ACTION

• Gases evaporating from cryogenic liquid releases are themselves colorless. However, the heat exchange taking place cools the air below its dew point, producing a water vapor fog. **Observation of an unanticipated fog requires immediate evacuation of the cryogenic area without further investigation**.

• Warm gas releases will not produce a fog, and the fog accompanying a cold release cannot be assumed to delineate the only volume occupied by the cryogenic fluid. The proper evacuation route is to move horizontally away from the fog back in the direction from which you approached when possible. Routes passing above, below, or to the side of the fog should be avoided.

 Hssssssss

Cryogenic fluid (liquid or gas) releases might be accompanied by pressure-venting sounds. **Hearing an unanticipated pressure-venting sound requires immediate evacuation of the cryogenic area without further investigation.**

• Not all releases will be accompanied by venting sounds. However, when a venting sound is heard, the proper course of evacuation is to move horizontally in the direction in which the sound is receding. Routes passing above, below, or to the side of the sound should be avoided.

OXYGEN MONITORING

• Oxygen-monitoring equipment and associated visual and audible alarms have been placed at the entrances to cryogenic areas, as well as in strategic locations within the cryogenic areas.

• A **green** systems status light on the visual alarm box means the equipment is functional.

• A flashing **blue** light on the visual alarm box means the oxygen level is below 19.5%. If inside, **evacuate the area immediately**. If outside, **do not enter**.

• An audible tone also sounds in the area when the oxygen level drops below 19.5%. All personnel, regardless of their activity, must **immediately evacuate**.

• A cryogenic **area must not be occupied or entered** without personnel protective devices or oxygen monitoring equipment in any case **when the system status light is not green** or the blue light is flashing.

LIQUID OR SOLID CONDENSATE

- **Liquid or solid condensate** produced at cryogenic temperatures should be considered to be **oxygen enriched** unless information to the contrary is known.

- **Clothing and equipment wetted by condensate** produced at cryogenic temperatures should be considered to be **oxygen enriched** unless information to the contrary is known.

- Keep organics and sources of ignition away from liquid or solid condensates that have been produced at cryogenic temperatures.

- Assume that clothing and equipment wetted by condensate produced at cryogenic temperatures is oxygen enriched for a minimum of 30 minutes after drying.

PERSONNEL PROTECTIVE EQUIPMENT

- Personnel protective equipment (PPE) for access to cryogenic areas carries no special requirements beyond those necessary for the hazards associated with the activity itself. For example, walking through the compressor room might require hearing protection.

- PPE for cryogenic work is specified in the job-specific hazard analysis.

When PPE is specified in a JSA for cryogenic work, certain types of materials and configurations are more suitable than others. There are also some basic requirements:

- Eyes – safety glasses at all times.
- Face – Add a full face shield where pressure releases are anticipated.
- Hands – Loose fitting gloves that can be easily removed, not fitted with large cuffs in which liquids can collect (leather or cryogenic specialty fabric).
- Clothing – Long trousers (without cuffs preferred) to be worn outside shoes. The less porous (tight weaves) the fabric the better.
- Shoes – No open or fabric shoes.

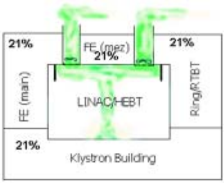
Questions People Have Been Asking

There is only one door out of the cold box lower level, and it is near the most likely area of a cryogenic release. Is the ladder from the cold box floor to the loading dock a proper emergency means of egress?

Yes. The ladder was determined to provide emergency egress requirements satisfying fire protection requirements for a “low-occupancy” facility. Similarly, the ladder provides an alternate means of exiting the cold box in case the floor level doorway be blocked by a cryogenic release.

Is there a risk of oxygen deficiency when I'm in the Klystron building?

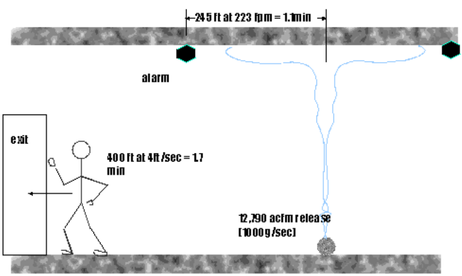
No. There are oxygen sensors in the super conducting portion of the LINAC where the helium is. If the helium leaks and sets off the alarms, the alarms also start the smoke removal system which exhausts the helium. The smoke removal system has enough capacity to prevent the helium from reducing oxygen to hazardous levels in other attached areas. This is true for the klystron, front end, HEBT, and ring.



If I'm in the linac and a release of helium occurs, will I have enough time to escape?

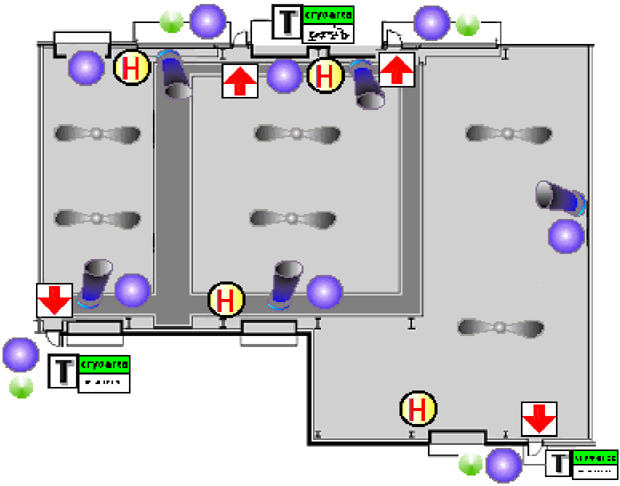
Yes. Helium releases in the linac should be accompanied by a water vapor fog and pressure-venting sounds, which could provide an early warning. Even if this doesn't happen, modeling results and test releases at other accelerators have demonstrated that cold helium rises, where it triggers the alarm system located along the ceiling. Once the helium triggers an alarm, the time to walk to an exit is much less than the time it takes for the oxygen concentration at the breathing zone to drop to hazardous levels.

Figure 2. Depiction of maximum alarm spacing



Exit time plus Alarm time is = Time to reach 16% oxygen with alarm spacing of 490 ft

Location of Cryogenic Safety Features in the Warm Compressor Room



Exit way

Oxygen deficiency warning light

Oxygen monitor status light

Oxygen deficiency warning horn

Oxygen sensor in high position

Backup oxygen sensor

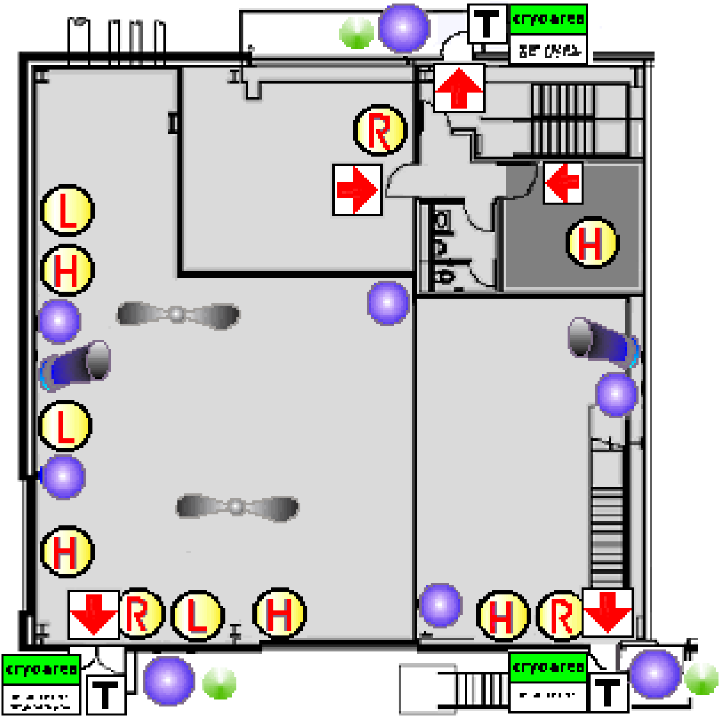
Cryogenic warning sign

Oxygen sensor in low position

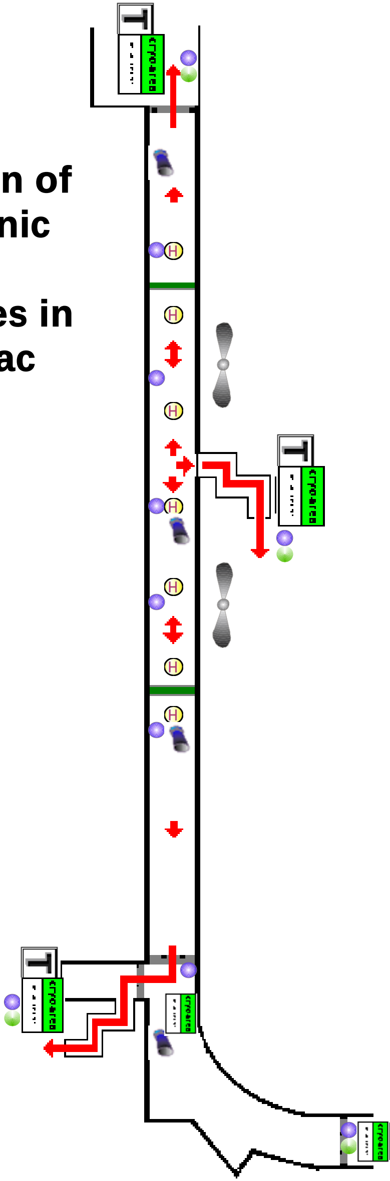
Air circulation fan

Training requirement for entry

Location of Cryogenic Safety Features in the Cold Box and Control Room



Location of Cryogenic Safety Features in the Linac



Standard Cryogenic Hazard Alerting Sign

Self-Evaluation

1. **I can name the principle hazards associated with cryogenic fluids.**
2. **I know where large quantities of cryogenic fluids are used at SNS.**
3. **I know the types of personnel protective equipment that could be required for work with cryogenic fluids.**
4. **I understand the warning signs, including alarms, and what to do in the event of a cryogenic release.**

Don't work with cryogens or in cryogenic areas without assistance unless you are comfortable with your knowledge of these important safety considerations.

Example Questions for Job Hazard Analyses (JHAs)

Task	Hazard	Persons at Risk	Avoidance/management
Entering facilities with complex cryogenic systems in place	• Depletion of oxygen, causing asphyxiation (ODH) • Flammability-explosion hazard from oxygen enrichment in frozen condensate	Any person entering such a facility	• Follow cryogenic procedures/ warning signs • Provide adequate ventilation for the amount of cryogenic liquid, or provide fixed or portable atmospheric monitoring, or use breathing air system • Maintain/check system integrity before entering • Complete release recognition/ avoidance training • Assume frozen condensate is oxygen enriched and treat as combustion hazard

Task	Hazard	Persons at Risk	Avoidance / management
Moving containers	• Overexertion • Slips/trips • Container damage, possibly causing leakage • (ODH)	• Personnel involved in transporting, filling, or decanting containers • Personnel in the vicinity	• Use mechanical aids • Get assistance • Check path of travel • Inspect container integrity after moving • Avoid handling large volumes and use in poorly ventilated space (e.g., elevators) • (other ODH actions as above)

Task	Hazard	Persons at Risk	Avoidance/management
Filling/ decanting/ making and breaking system connections during maintenance and operation	• Splashes and spills. Low temperature of liquid causes severe burn-like damage to skin – comparable to damage caused by boiling water to the eyes and lungs • Insertion of hollow objects (tubes) causes liquid to spout out top • Decanting into improper containers (shatter/ rupture) • Some containers/ vents can become sealed by ice plugs • ODH	• Personnel handling the cryogenic fluid	• Wear cryogenic gloves • Wear safety glasses, goggles, or face shields if splashing/spurting is likely • Wear long sleeves, no open shoes, tight weave fabrics, no pockets/cuffs to catch and contain liquid next to skin • Use mechanical aids when possible • Don't place hollow tubes in cryogen • Decant into containers designed for cryogenic fluids only. Plastics and rubber could become brittle and break unexpectedly • Follow safe techniques for dispensing and transferring liquid cryogens standard operating procedures • Minimize moisture incursion in systems/ containers • Follow ODH avoidance actions, as above

Task	Hazard	Persons at Risk	Avoidance / management
Contact with cryogenic containers/ system components (incidental or during maintenance and operation)	• Skin may freeze and adhere to surfaces	• Personnel in areas where cryogens are used	• Avoid direct skin contact with cryogenic equipment or surfaces that have recently been in contact with cryogenic liquid • Label items where not obvious
Using cryogens to cool other containers/ materials	• Vials/ vessels stored in liquid cryogen could explode when brought to room temperatures	• Personnel handling the vessels, as well as personnel in proximity	• Wear face shields or goggles • Prottect skin with cryogenic gloves and clothing, as above

How much gas is left in this cylinder?

$$Contents_{remaining} = Contents_{full} \, x \, \frac{Pressure_{remaining}}{Pressure_{full}}$$

Argon cylinder DOT 3AA-2265 psia and 10% overfill (psia=1.1x2265=2492) contains 280 scf at 70˚F. What is the cylinder content at 1000 psia?

$$Contents_{remaining} = 280x\frac{1000}{2492} \approx 112scf$$

Note: with liquefied compressed gases, cylinder content can be determined only by weight.

Quick Estimate of Oxygen Concentration

The equation for estimating oxygen concentration in the work area if the contents of a vessel or cylinder are released:

$$\text{Resulting \% oxygen} = \frac{21(v_r - v_g)}{v_r}$$

Where:

v_r = volume of the room

v_g = volume of the gas

The resulting oxygen concentration must be at least 19.5%.

The volume of compressed gas bottles can range from 200-300 ft^3 depending on the gas and the type of cylinder. If a more accurate number is needed, check with the gas supplier.

For a cryogenic container, the gas volume is the liquid volume times the expansion ratio for the particular material.

Example:

full 50-liter Dewar of LN2, (50 liters)/(28.3liters/ft^3)=1.77 ft^3 LN2

Volume of gas is (694 ft^3 of gas/ft^3 LN2)(1.77 ft^3 LN2) = 1232 ft^3 (754:1 for helium)

Volume of lab (20 x 30 x 9 ft) = 5400 ft^3

$$\text{Resulting \% oxygen} = \frac{21(5400 - 1232)}{5400} = 16.2\%$$

Cryogenic Liquid Cylinder Dimensions and Capacities (nominal 180 Liter) DOT Specification: 4L (model XL-45)			
Nominal Dimens. (inches)	20x61	20x61	20x61
Approx. Weight-Empty (lbm)	255	255	255
Pres. Relief Valve Setting (psig)	<26	235	350
Oxygen Capacity	180 liters 453 lb 5472 scf	164 liters 412 lb 4088 scf	158 liters 399 lb 4820 scf
Nitrogen Capacity	173 liters 308 lb 4250 scf	166 liters 296 lb 4088 scf	157 liters 280 lb 3864 scf
Argon Capacity	N/A	161 liters 494 lb 4775 scf	159 liters 487 lb 4709 scf

Liquid Helium Containers (2000 liters or less)						
Item	Minimum Net Cap. (A)	Maximum Tare Weight (B)	Maximum Height/ Width (C)	Maximum N.E.R. (C,D).	Minimum Neck Access Dia	Minimum Gas Vent scfh (E)
A	30 liters	120 lb	52"/24"	2.75%	1/2"	4000
B	60 liters	200 lb	52"/24"	2.00%	1/2"	4000
C	100 liters	260 lb	60"/26"	1.25%	1/2"	4000
D	250 liters	500 lb	70"/32"	1.00%	3/4"	8000
E	500 liters	820 lb	72"/42"	1.00%	3/4"	8000
F	1000 liters	1600 lb	72"/55"	1.00%	3/4"	8000
G	2000 liters	2400 lb	88"/60"	1.00%	3/4"	8000

Industrial Gas Cylinder Capacities

Nominal Dimensions w/o valve	Argon CGA 580 valve		Helium CGA 580 valve		Nitrogen CGA 580 valve	
	Full Capacity (ft³)		Full Capacity (ft³)		Full Capacity (ft³)	
	STP	10% overfill	STP	10% overfill	STP	10% overfill
5.75”x 32”	57	63	51	56	53	58
5.75”x 32”	57	63	51	56	53	58
5.75”x 37”	57	63	51	56	53	58
5.75”x 37”	57	63	51	56	53	58
7”x 32”	83	92	74	81	77	85
7”x 32”	83	92	74	81	77	85
7”x 43”	113	125	100	110	105	115
7”x 43”	113	125	100	110	105	115
7”x 43”	127	140	112	122	117	128
7.25”x 46”	141	155	124	136	131	143
9”x 51”	227	250	201	219	210	230
9”x 51”	227	250	201	219	210	230
9”x 51”	255	280	224	244	234	255
9.25”x 55”	305	336	267	291	279	304