

# Chapter 36

## Cryogenic and Oxygen Deficiency Hazard Safety

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# 1 Overview

*Cryogenics* are super-cooled substances, typically stored in liquid form, that are used to cool other materials to extremely low temperatures. Cryogenic equipment is used to support the photon science and high-energy physics program here at the SLAC National Accelerator Laboratory by maintaining certain beam line and accelerator equipment at cryogenic temperatures. Cryogenics may be present in the accelerator housing, the end stations, the refrigeration units and their support buildings, Central Lab facilities, and SPEAR3. Cryogenics may also be present anywhere portable cryogen containers can be transported.

Cryogenics used at SLAC include liquid nitrogen, liquid helium, liquid carbon dioxide, liquid argon, and liquid hydrogen. Physical properties of cryogenics commonly used at SLAC are noted in Cryogenic and Oxygen Deficiency Hazard Safety: Physical Properties of Common Cryogenics (see Section 6, "Exhibits"). These liquefied gases have the property that, if they warm to a temperature above their boiling point, their volume increases by a factor of seven to nine hundred times. The resulting large volume of gas can displace part or all of the air in an unventilated enclosure, thereby creating a potential for asphyxiation for persons entering the enclosure. This hazard is particularly serious in enclosed volumes that have no vents or ventilation systems. The chapter also addresses oxygen deficiency hazards (ODHs) that may result from boil-off gas and non-cryogen compressed gas use.

The typical daily site-wide cryogen inventory includes (in liquid liters):

- Nitrogen 75,000
- Helium 8,000
- Carbon dioxide 5,000

Liquid nitrogen is by far the cryogen in greatest usage at the facility.

*Note* Liquid oxygen is not used in significant quantities at SLAC, but can be produced as an unwanted by-product through the interaction of air with the surface of exposed piping colder than 80 K.

## 1.1 Hazards / Impacts

Cryogenic hazards at SLAC fall into these general categories:

- *Cold burns* (frostbite)
- Pressure explosions
- Chemical explosions or exposures (when hydrogen is present)
- *Oxygen deficiency hazard* (ODH), also known as asphyxiation
- Other atmospheric hazards

### 1.1.1 Cold Burns

The most likely cause of cold burns to the hands and body is through contact with metal surfaces at extremely cold temperatures. Cold burns can occur almost instantaneously, especially when the skin is moist.

The damage from cold burns occurs as the affected tissue thaws. Intense *hyperemia* (abnormal accumulation of blood) usually takes place in the affected areas. Additionally, a blood clot may form along with an accumulation of body fluids, which decreases the local circulation of blood. If the consequent deficiency of blood supply to the affected cells is extreme, tissue decay may result. Also, cooling of the internal organs of the body can disturb normal functioning, producing a dangerous condition known as hypothermia. It is very dangerous to cool the brain or heart.

### 1.1.2 Pressure Explosions

A pressure explosion can be caused by cryogenic temperatures either through material degradation or inadequate pressure relief.

Cryogenic temperatures drastically affect the properties of solid materials. Materials can become brittle, or shrink beyond design limits, to cause leaks that are not detectable at room temperature. The ability of materials to withstand long-term exposure to cryogenic temperatures must be carefully investigated to avoid material degradation.

Because material cracks can more easily develop at cryogenic temperatures, any volume cooled externally by a cryogen or any vacuum spaces in contact with cryogen must have the ability to relieve pressure. Cryogen or air may leak into a sealed space through such cracks. Some atmospheric gases will condense under such conditions and exist as a cryogen in the sealed space. Upon warming, these cracks may be too small to vent the gas, and the contained, expanding fluid can shatter the vessel.

### 1.1.3 Chemical Explosions

The chemical properties and reaction rates of substances are influenced by cryogenic conditions. Condensing a cryogen from a pure gas at room temperature will concentrate the material typically 700 to 800 times its room temperature density. Oxygen-enriched air produced by either liquid helium or nitrogen has many of the same properties as liquid oxygen. Liquid oxygen, for example, can react explosively with materials usually considered to be noncombustible.

Cryogenic fluids with a boiling point below that of liquid oxygen have the ability to condense oxygen out of the air if exposed to the atmosphere. This is particularly troublesome if a stable system is replenished repeatedly to make up for evaporation losses as oxygen may accumulate as an unwanted contaminant. Violent reactions (for example, rapid combustion or explosions) may occur if the material is not compatible with liquid oxygen.

Oxygen enrichment will also occur if liquefied air is permitted to evaporate (oxygen evaporates less rapidly than nitrogen). Oxygen concentrations of 50 percent may be reached near evaporating liquid air. Also, condensed air dripping from the exterior of cryogenic piping will be rich in oxygen. Atmospheric oxygen concentrations above 23.5 percent pose a significant hazard.

Small quantities (less than 100 liters) of liquid hydrogen have been used for experimental targets in End Station A and are supported by a gas storage area behind the end station. This hydrogen is confined to a

small cryogenic target volume and cooled with a helium refrigeration unit. Local ventilation in the immediate vicinity of the containment is required to ensure that hydrogen levels do not exceed 10 percent of its *lower explosive limit* (LEL). Releases of hydrogen gas from the system are unlikely as the containment system is designed to keep the hydrogen at the target cryostat through multiple containment layers. However, if a containment failure occurs, an immediate combustion hazard can develop.

#### 1.1.4 Oxygen Deficiency Hazards

An oxygen deficiency hazard (ODH) exists when the concentration of oxygen is equal to 19.5 percent or less (by volume) at a typical barometric pressure of 760 mm Hg.

Without adequate oxygen, one can lose consciousness in a few seconds and die of asphyxiation in a few minutes. (See Section 6, “Exhibits”, Cryogenic and Oxygen Deficiency Hazard Safety: ODH Risk Assessment Procedures, Table 1, for the biological effects of reduced oxygen concentrations.)

Liquefied gases can easily and quickly create an ODH. When expelled to the atmosphere at room temperature, liquefied gases evaporate and expand 700 to 800 times their liquid volume. Consequently, leaks of even small quantities of liquefied gas can displace large amounts of oxygen, and thereby render an atmosphere lethal.

Dense gases (those with densities significantly greater than atmospheric air at STP) will fill pits and other low areas. Examples of dense gases include various freons, sulfur hexafluoride, and certain cold cryogenics. The greater the gas density, the greater the oxygen displacement and the longer the time required for the gas to dissipate.

“Air dense” gases (those with densities approximating atmospheric air at STP) may be used at SLAC in sufficient quantities that they could dilute the available oxygen in a room/enclosed work area. Examples of air dense gas include nitrogen and argon. This hazard is especially prevalent where boil-off nitrogen is used as a vacuum system purge in clean room environments. Failure of the HVAC system normally in use in such locations (due to maintenance shutdown or power outage) can result in accumulation of gas sufficient to create a hazard, even without any failure of any part of the gas handling system.

Light gases (those with densities significantly lesser than atmospheric air at STP) can affect the areas above a cryogen spill. Examples of light gases include helium and hydrogen. Spill experiences at the Fermi and Jefferson laboratories reveal that even with a connecting shaft of only a few square inches, an ODH can arise at a factor of ten in the building above compared with an area three feet horizontally from the spill. Another potential hazard from a cryogen spill can arise with poor outdoor venting, which can produce a more localized ODH.

Users of cryogenics and gases that can create ODHs should always be aware of the possibility that localized ODH conditions can exist. An example would be where use of a welding purge gas is exhausted in such a way that oxygen is displaced from between the welder’s face shield and his or her body, creating an oxygen deficiency in the breathing space.

#### 1.1.5 Other Atmospheric Hazards

Atmospheric hazards are commonly associated with confined spaces. See Chapter 6, “Confined Space”, for more information.

Gases in use at SLAC besides those mentioned previously include isobutane, freons such as R-12 and R-22, H-134a, particle detector gas mixtures, and halons associated with special area fire suppression systems.<sup>1</sup> Any of these gases may give rise to atmospheric hazards under certain circumstances. Collectively with the gases that may arise from cryogenic system operation, these gases may be termed *non-life supporting gases*.

## 2 Scope

This chapter applies to all work involving cryogenics and non-life supporting gases at SLAC.

All proposed new uses of these materials must meet the requirements of this chapter. All existing uses of these materials at the time of chapter adoption will be allowed on a continuing basis, until one year from the adoption of the chapter, provided that no incidents or close calls are experienced with respect to a particular use. Afterwards, all existing uses must either be shown to be exempt from the chapter requirements by their line sponsors or must follow the chapter requirements (including HEEC review, control requirements, and signage).

### 2.1 Exemptions

[ This section is currently under revision. For questions regarding exemptions please contact the cryogenic and oxygen deficiency hazard safety program manager, Mike C. McDaniel, at ext. 5015 or [hazmat1@slac.stanford.edu](mailto:hazmat1@slac.stanford.edu). ]

## 3 Standards

There are no federal, state, or local laws or regulations directly applicable to cryogenic and ODH safety. The requirements set forth in this chapter were derived primarily from requirements in use at other high-energy physics laboratories in the United States, including Jefferson, Fermi, and Sandia (see Section 7, "References").

## 4 Definitions

*American Society of Mechanical Engineers (ASME)*. A standards-setting body for mechanical and pressure equipment

*Cryogen*. A super-cooled substance (usually liquid) used to cool other materials to extremely low temperatures

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<sup>1</sup> For more information, contact the SLAC fire marshal (ext. 4509) or the SLAC fire technician (ext. 4013).

*Cryostat.* An apparatus used to maintain a constant low temperature

*Dewar.* Approved container for storing cryogenes

*Non-life supporting gas.* A gas or gaseous mixture that presents insufficient oxygen to sustain human respiration

*Oxygen deficiency hazard (ODH).* An oxygen concentration equal to 19.5 percent or less (by volume) of dry air at a typical barometric pressure of 760 mm Hg

*ODH hazard classes.* Classification system that defines access restrictions and required controls<sup>2</sup>

- *ODH 0.* Hazard classification for areas with an estimated ODH fatality risk of less than  $10^{-7}$ /hr
- *ODH 1.* Hazard classification for areas in which, without countermeasures, the fatality risk from an ODH is less than  $10^{-5}$ /hr
- *ODH 2 and ODH 3.* Hazard classification for areas with an ODH fatality risk of greater than  $10^{-5}$ /hr
- *ODH 4.* Hazard classification for areas that require the use of a self-contained breathing apparatus

*Standard temperature and pressure (STP).* Standard temperature and pressure conditions, which are the reference conditions for which the physical and chemical properties of a gas are normally given. Standard temperature = 25 deg C (298 deg K) and standard pressure = 1 atmosphere (760 mm Hg).

## 5 Requirements

### 5.1 General

#### 5.1.1 ODH Hazard Classification

All work areas at which cryogenes are stored and/or used will be classified as ODH 0, ODH 1, ODH 2, ODH 3, or ODH 4, with ODH 0 being the area of lowest risk and ODH 4 being the area of highest risk. Each type of area will be clearly signed.

#### 5.1.2 Approval Requirements

All work areas at which cryogen usage is proposed above the de minimis threshold set forth in Section 2, “Scope”, and any other work areas at which other non-supporting life gas usage is proposed, must obtain written approval from the Hazardous Experimental Equipment Committee (HEEC)<sup>3</sup> prior to implementation (See Section 5.2.3, “ODH Area Classification and Inventory”).

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2 For requirements, see Cryogenic and Oxygen Deficiency Hazard Safety: ODH Control Requirements (SLAC-I-730-0A06S-002), <http://www-group.slac.stanford.edu/esh/eshmanual/references/cryogenicsODHControls.pdf>

3 “Hazardous Experimental Equipment Committee”, <https://www-internal.slac.stanford.edu/esh/committees/heec/default.htm>

All use of non-personal oxygen deficiency monitors (that is, all permanent and/or statically placed monitors) must be registered with the cryogenic and ODH safety program manager. Each line organization that owns such monitors (Facilities Cryogenic Operations Group, SSRL hutch managers, MFD welding managers) is responsible for stating where such monitors are located, who is responsible for calibrating the monitors, and what sort of power backup each monitor has, if any. The primary driver for collecting such information is the establishment of a site-wide master list (inventory and map) of fixed monitors for emergency response purposes. This master list is necessary for authorizing re-entries into site work areas following unanticipated utility outages and emergencies, such as the May 2005 three-day, site-wide power outage.

### 5.1.3 Hazard Mitigation

Control requirements tailored to the ODH hazard classification of the work area (see Section 6, "Exhibits", Cryogenic and Oxygen Deficiency Hazard Safety: ODH Control Requirements) and any engineering controls specified by the HEEC pre-operating approval must be implemented prior to starting operations.

### 5.1.4 Roles and Responsibilities

#### 5.1.4.1 Cryogenic and Oxygen Deficiency Hazard Safety Program Manager

- Performs risk assessments for new and modified cryogenic installations
- Prepares ODH calculations and recommends ODH hazard classifications
- Provides signage and related support to area/facility owners
- Maintains an inventory of the various ODH hazard areas
- Develops cryogenic and ODH safety training
- Serves as secretary of the HEEC

#### 5.1.4.2 Hazardous Experimental Equipment Committee

- Specifies engineering controls for new and modified cryogenic installations
- Specifies ODH hazard classification for cryogenic installations
- Issues pre-operating and operating approvals of new and modified cryogenic installations
- Performs audits of ODH areas to ensure compliance with approvals

#### 5.1.4.3 Facilities Department, Cryogenic Operations Group

- Provides technical support in the design and safe operation of cryogenic systems
- Maintains an inventory of the fixed oxygen monitors in use site-wide
- Maintains and calibrate fixed oxygen monitors (not including SSRL hutch monitors)
- Maintains and calibrate personal oxygen monitors (not including Field Safety and Building Inspection [FSBI] Office monitors)

#### 5.1.4.4 SSRL Hutch Managers

- Maintain and calibrate fixed oxygen monitors in SSRL beam line hutches

#### 5.1.4.5 Confined Space Program Manager

- Serves as backup for the cryogenic and ODH safety program manager on signage issues
- Serves as additional resource for provision of personal oxygen monitors and maintenance and calibration for fixed and personal oxygen monitors
- Maintains on the web a map of the various ODH hazard areas
- Maintains and calibrates FSBI-owned personal oxygen monitors

#### 5.1.4.6 Industrial Hygiene Program Manager

- Provides guidance and recommendations on personal protective equipment (PPE) to be used at specific cryogen dispensing facilities, and for cryogen usage in general

#### 5.1.4.7 Managers and Supervisors

- Ensure that ODH and cryogenic hazards are identified, classified, and properly posted
- As with any other hazard, ensure that workers are appropriately trained and qualified prior to performing operations with cryogenic or ODH risks
- Ensure operations do not exceed any limits contained in HEEC operating approvals
- Approve and supervise all hazardous cryogenic repair procedures
- Technically validate work control documents with cryogenic hazards (work authorization)
- Conduct ODH risk assessments when delegated by HEEC

#### 5.1.4.8 Personnel

All personnel (SLAC employees, users, visitors, and subcontractors) will

- Observe and follow all posted ODH restrictions

## 5.2 Procedures and Specific Requirements

### 5.2.1 ODH Risk Assessments

Before establishing a cryogenic work area, an ODH risk assessment must be performed. The assessment must include calculations to determine whether the proposed storage and use of the cryogen will create an ODH in the event of the worst possible accident. The guidelines to be followed during these risk assessments are shown in Section 6, "Exhibits", Cryogenic and Oxygen Deficiency Hazard Safety: ODH Risk Assessment Procedures. Each ODH risk assessment must be approved by HEEC.

Special care must be taken to examine the areas at elevations below (pits, trenches, tunnels) and above (such as service buildings, crane cabs, and roof maintenance areas) the elevation at which cryogenics are being stored and used, depending on the physical properties of the cryogen.

### 5.2.2 Engineering Controls

Since cryogenic fluids exist as liquids only at temperatures considerably below room temperature, full containment of the fluid at room temperature is usually not feasible. Normal storage facilities and piping

systems must allow for unavoidable heat input from the environment. For ordinary operations this means appropriate insulation, adequate pressure-relief devices, and proper disposal or recycling of the gases. (See Section 6, "Exhibits", Cryogenic and Oxygen Deficiency Hazard Safety: ODH Control Requirements, for details on environmental, engineering, and personal controls of cryogenic hazards.)

#### 5.2.2.1 Insulation

Certain cryogens, such as helium and hydrogen, are cold enough to solidify atmospheric air. Entry of air into cryostats containing these cryogens can be prevented by pressurizing the system. If openings to the atmosphere exist, they are likely to become plugged by solidified air, leading to overpressure and vessel failure. Such conditions will also result in hazardous contamination of the fluid. Again, adequate pressure-relief devices must be provided to vent all gas that could be produced during a theoretical maximum heat flux into the system. The system configuration must ensure that any air that enters the cryostat and freezes cannot prevent proper functioning of pressure relief devices.

Unless these fluids are handled in vacuum-jacketed vessels and piping, air will condense on the exterior of the system. This condensate will be rich in oxygen. Hazards are created by the exposed cold surfaces, dripping liquid air, and the potential for exploding insulation. The latter can happen when air condenses between the metal surface and the insulating layer. On warming, the air vaporizes and can rip off the insulation with explosive force. Such insulation systems must be specially engineered to prevent air penetration, or the insulation must have sufficiently low strength that it will yield at low gas pressure.

#### 5.2.2.2 Pressure Relief

Heat flux into the cryogen is unavoidable regardless of the quality of the insulation installed. Pressure relief must be provided to permit routine release of gas vapors generated by this heat input. Typically such relief is best provided by rated spring-loaded relief devices or an open passage to the atmosphere with a check valve.

Additional relief devices should be provided as backup to the operational relief when the capacity of the operational relief device is not adequate to take care of unusual or accidental conditions. This may be the case if the insulation is dependent on the maintenance of a vacuum in any part of the system (this includes permanently sealed dewars), if the system may be subject to an external fire, or if rapid exothermic (heat releasing) reactions are possible in the cryogen or a container cooled by the cryogen. In each case, relief devices capable of handling the maximum volume of gas that could be produced under the most adverse conditions must be provided.

Each and every portion of the cryogenic system must have uninterruptible pressure relief. Any part of the system that can be valved off from the remainder must have separate and adequate provisions for pressure relief.

Examples of parts that usually require separate relief systems include

- Pressurized supply dewars
- Piping (except ambient) and manifolds
- Tubing and hoses used to transfer a cryogen, unless an air gap is provided
- Bath space surrounding experimental volume
- Any volume cooled externally by a cryogen
- Vacuum spaces in contact with cryogen

Pressure-relief devices must not be set higher than the containment's maximum allowable working pressure. It is further required that this pressure rating can be met with the usual safety at the temperature of minimum strength, and that embrittlement under cryogenic conditions be within acceptable limits.

Specific requirements exist for room temperature systems (oil-removal systems and gas-storage yards, located at the central helium facility and research yard), and the BaBar helium liquefier. These systems operate at medium pressure (15–20 atmospheres), and only ASME code-stamped vessels are used. Only ASME code-rated reliefs or rupture disks can be used to relieve pressure for these vessels.

#### 5.2.2.3 Material Specifications

All parts in contact with the cryogenics must be appropriate for cryogenic service. This is applicable for all operational modes of the cryogenic system. Assistance in selecting the appropriate materials will be provided by the Cryogenic Operations Group upon request. Appropriate material use will be checked as part of HEEC reviews.

In certain cases, HEEC reviews can provide a design basis for an exception from this requirement, for example niobium accelerator cavities that operate in direct contact with cryogenics; experience with this material combined with careful design of containment systems renders niobium an acceptable material choice in this case even though Niobium metal is not rated for this use.

#### 5.2.2.4 System Interlocks

Several systems at SLAC make use of interlocks to either prevent entry or shut off gas flow when undesired operating conditions exist. Examples of such systems include the “short” NLCTA clean room in End Station B and a Group E laboratory in the Central Annex. In one such type of interlock, the absence of makeup air (say, for instance, due to a failure of the local HVAC system) disable a nitrogen boil-off purge gas and thus serves as an engineering control on the hazard. In another, a fixed alarm would be interlocked in a feedback loop to the supply valve and shut off the flow of gas in the system. Each cryogenic system is unique and the use of interlocks should be considered whenever feasible.

### 5.2.3 ODH Area Classification and Inventory

Following conduct of the ODH risk assessment and review of the proposed engineering controls, HEEC will issue a *pre-operational approval* and/or an *operational approval* (subject to certain conditions) to the project sponsors.<sup>4</sup> The cryogenic and ODH safety program manager, who serves as the HEEC secretary, will make a determination as to which of the ODH hazard classifications (ODH 0 through ODH 4) will be applied to the cryogenic work area. These classifications are subject to review by HEEC and will be approved in writing. The classification decision in turn will result in specification of which hazard mitigation procedures are necessary to be followed for the subject work area. (See Section 6, “Exhibits”, Cryogenic and Oxygen Deficiency Hazard Safety: ODH Control Requirements, for which controls are applicable to which of the different area classifications.)

Following classification determination, the specified controls will be implemented and the cryogenic work area will be posted by the area/facility manager with signs corresponding to the degree of ODH hazard. Signs may be obtained from either the Cryogenic and Oxygen Deficiency Hazard Safety program manager

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4 For example approvals, see “Hazardous Experimental Equipment Committee: Operational Approvals”, <https://www-internal.slac.stanford.edu/esh/committees/heec/>.

or the confined space program manager; these individuals will be available to assist with signage as necessary. (See Section 6, “Exhibits”, Cryogenic and Oxygen Deficiency Hazard Safety: ODH Signs.)

The cryogenic and ODH safety program manager will maintain an inventory of ODH areas and their classifications and make it available through the web. This inventory will be updated whenever an official HEEC record of decision is entered. (For a snapshot of the ODH area inventory on the date of chapter publication, see Section 6, “Exhibits”, Cryogenic and Oxygen Deficiency Hazard Safety: ODH Locations.) The confined space program manager will assist the cryogenic and ODH safety program manager with mapping the ODH areas and all permanently installed atmospheric monitoring equipment and making these maps available for use by all parties.

#### 5.2.4 Cryogen Dispensing and Usage

Cryogen storage facilities of all sizes and scale exist at SLAC. Many of these facilities have dispensing capabilities. As examples, liquid nitrogen from a bulk storage tank may be transferred to a trailer-mounted tank or from a dewar to a small research sample preparation container.

Eye, hand, and body protection are necessary to prevent potential cold burns when handling cryogens.

It is the responsibility of line managers and supervisors to ensure that PPE appropriate to the size and scale of the dispensing system is readily known to all operators. A solution in use at several facilities simply posts in picture format the PPE required for dispensing operations at that location. The industrial hygiene program manager is available to assist line managers and supervisors in making such determinations.

#### 5.2.5 General Cryogen Hazard Prevention and Response Guidelines

See Section 6, “Exhibits”, Cryogenic and Oxygen Deficiency Hazard Safety: General Guidelines.

### 5.3 Training

#### 5.3.1 Personnel

For personnel who work directly with cryogenic liquids or gases (usually nitrogen, argon, or helium), use systems/equipment that contain cryogenic liquids (excluding commercial refrigerators), have direct managerial control over areas and/or personnel who use these materials, or whose primary work area includes any ODH classification placard, the required course is the following:

- ES&H Course 170, Cryogenic and Oxygen Deficiency Safety Training<sup>5</sup>

#### 5.3.2 Visitors

Visitors who will only be entering areas designated as ODH-0 and ODH-1 must be given a hazard awareness briefing by the area supervisor prior to entry. The briefing must include the location of potential oxygen deficiency sources, alarms, and the protocol for responding to off-normal events.

Any visitor who will be entering an area designated as ODH-2 and ODH-3 must complete

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5 [https://www-internal.slac.stanford.edu/esh-db/training/slaonly/bin/catalog\\_item.asp?course=170](https://www-internal.slac.stanford.edu/esh-db/training/slaonly/bin/catalog_item.asp?course=170)

- ES&H Course 170, Cryogenic and Oxygen Deficiency Safety Training<sup>6</sup>

## 6 Exhibits

- Hazardous Experimental Equipment Committee Charter<sup>7</sup>
- Cryogenic and Oxygen Deficiency Hazard Safety: ODH Control Requirements (SLAC-I-730-0A06S-002)<sup>8</sup>
- Cryogenic and Oxygen Deficiency Hazard Safety: ODH Risk Assessment Procedures (SLAC-I-730-0A06C-001)<sup>9</sup>
- Cryogenic and Oxygen Deficiency Hazard Safety: ODH Hazard Classification Signs (SLAC-I-730-0A06S-003)<sup>10</sup>
- Cryogenic and Oxygen Deficiency Hazard Safety: Classified ODH Locations (SLAC-I-730-0A06S-004)<sup>11</sup>
- Cryogenic and Oxygen Deficiency Hazard Safety: Physical Properties of Common Cryogenics (SLAC-I-730-0A06S-005)<sup>12</sup>
- Cryogenic and Oxygen Deficiency Hazard Safety: General Guidelines (SLAC-I-730-0A06S-006-R000)<sup>13</sup>
- Cryogenic and Oxygen Deficiency Hazard Safety: Personal Protective Equipment Requirements (SLAC-I-730-0A06S-007)<sup>14</sup>

## 7 References

*SLAC Environment, Safety, and Health Manual* (SLAC-I-720-0A29Z-001)<sup>15</sup>

- Chapter 6, “Confined Space”<sup>16</sup>

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6 [https://www-internal.slac.stanford.edu/esh-db/training/slaonly/bin/catalog\\_item.asp?course=170](https://www-internal.slac.stanford.edu/esh-db/training/slaonly/bin/catalog_item.asp?course=170)

7 <https://www-internal.slac.stanford.edu/esh/committees/heec/charter.htm>

8 <http://www-group.slac.stanford.edu/esh/eshmanual/references/cryogenicsODHControls.pdf>

9 <http://www-group.slac.stanford.edu/esh/eshmanual/references/cryogenicsODHRiskAssessment.pdf>

10 <http://www-group.slac.stanford.edu/esh/eshmanual/references/cryogenicsODHSigns.pdf>

11 <http://www-group.slac.stanford.edu/esh/eshmanual/references/cryogenicsODHLocations.pdf>

12 <http://www-group.slac.stanford.edu/esh/eshmanual/references/cryogenicsProperties.pdf>

13 <http://www-group.slac.stanford.edu/esh/eshmanual/references/cryogenicsGuidelines.pdf>

14 <http://www-group.slac.stanford.edu/esh/eshmanual/references/cryogenicsPPE.pdf>

15 <http://www-group.slac.stanford.edu/esh/eshmanual/>

16 [http://www-group.slac.stanford.edu/esh/hazardous\\_activities/confinedspace/policies.htm](http://www-group.slac.stanford.edu/esh/hazardous_activities/confinedspace/policies.htm)

- Chapter 12, “Fire and Life Safety”<sup>17</sup>
- Chapter 14, “Pressure, Vacuum, and Cryogenic Systems”<sup>18</sup>
- Chapter 19, “Personal Protective Equipment”<sup>19</sup>
- Chapter 37, “Emergency Management”<sup>20</sup>
- Chapter 40, “Hazardous Materials”<sup>21</sup>

Other laboratories

- *Jefferson Lab Environment, Health and Safety Manual*, Chapter 6500, “Cryogenic and ODH Safety”<sup>22</sup>
- *Fermilab Environment, Safety, and Health Manual*, Chapter 5064, “Oxygen Deficiency Hazards”<sup>23</sup>
- Sandia Human Reliability Analysis

## 8 Implementation

The requirements of this chapter are effective upon publication unless otherwise noted here.

## 9 Ownership

Department: Field Safety and Building Inspection

Program: Cryogenic and Oxygen Deficiency Hazard Safety

Owner: Program Manager

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17 [http://www-group.slac.stanford.edu/esh/general/fire\\_safety/policies.htm](http://www-group.slac.stanford.edu/esh/general/fire_safety/policies.htm)

18 [http://www-group.slac.stanford.edu/esh/hazardous\\_activities/pressure/policies.htm](http://www-group.slac.stanford.edu/esh/hazardous_activities/pressure/policies.htm)

19 <http://www-group.slac.stanford.edu/esh/general/ppe/policies.htm>

20 <http://www-group.slac.stanford.edu/esh/emergency/chapter/policies.htm>

21 [http://www-group.slac.stanford.edu/esh/hazardous\\_substances/haz\\_materials/policies.htm](http://www-group.slac.stanford.edu/esh/hazardous_substances/haz_materials/policies.htm)

22 <http://www.jlab.org/ehs/ehsmanual/6000.html#s6500>

23 <http://www-esh.fnal.gov/FESHM/5000/5064.pdf>



# Cryogenic and Oxygen Deficiency Hazard Safety: ODH Control Requirements

Department: Field Safety and Building Inspection

Program: Cryogenic and Oxygen Deficiency Hazard Safety

Owner: Program Manager

Authority: ES&H Manual, Chapter 36, Cryogenic and Oxygen Deficiency Hazard Safety<sup>1</sup>

For all new and modified installations subject to the requirements of Chapter 36, “Cryogenic and Oxygen Deficiency Hazard Safety”, a quantitative risk assessment will be performed by the cryogenic safety program manager, or his/her designee, and reviewed by the Hazardous Experimental Equipment Committee (HEEC). HEEC will issue pre-operational and operational approvals for cryogenic operations as appropriate. For more information on this process, please refer to the HEEC web site.<sup>2</sup>

Locations with potential oxygen deficiency hazards (ODH) resulting from cryogen storage and use will be classified according to their degree of hazard, with ODH hazard category zero (ODH 0) being the category of least hazard and ODH hazard category four (ODH 4) being the category of greatest hazard. Control practices appropriate to the degree of hazard will be required. These control practices fall into the following categories:

- Environmental and engineering controls
- Personnel controls
- Emergency controls

The minimum control measures required for each ODH classification are shown in Table 1. These minimum controls must be implemented to reduce the fatality risk from an ODH to no more than  $10^{-7}$  per hour.

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1 *SLAC Environment, Safety, and Health Manual* (SLAC-I-720-0A29Z-001), Chapter 36, “Cryogenic and Oxygen Deficiency Hazard Safety”, [http://www-group.slac.stanford.edu/esh/hazardous\\_substances/cryogenic/policies.htm](http://www-group.slac.stanford.edu/esh/hazardous_substances/cryogenic/policies.htm)

2 “Hazardous Experimental Equipment Committee”, <https://www-internal.slac.stanford.edu/esh/committees/heec/default.htm>

# Cryogenic and Oxygen Deficiency Hazard Safety: ODH Control Requirements

Table 1 Required ODH Control Measures

	ODH Hazard Class				
	0	1	2	3	4
<b>Environmental and Engineering Controls</b>					
1. Warning signs	X	X	X	X	X
2. Installed oxygen monitor			X	X	X
3. Ventilation		X	X	X	N/A
4. Relief valves and piping arrangements – as required by HEEC					
<b>Personnel Controls</b>					
<b>Routine</b>					
5. Completed ESH Course 170, Cryogenic and Oxygen Deficiency Safety Training <sup>3</sup>	X	X	X	X	X
6. Personal oxygen monitor			X	X	X
7. Multiple person team (two-person rule)				X	X
8. Unexposed observer (three-person rule)				X	X
9. Self-contained breathing apparatus					X
10. Medical approval as ODH qualified					X
<b>Non-routine/Visitors</b>					
11. ODH hazard awareness briefing for visitors	X	X	N/A	N/A	N/A
12. One-to-one escort by ODH trained personnel		X	N/A	N/A	N/A

X = required

N/A = non applicable

## ***Environmental Controls and Engineering Controls***

1. Appropriate ODH warning signs, specific to the ODH level of hazard, will be posted at all entrances to warn potentially exposed individuals. The form of the signs is shown in Cryogenic and Oxygen Deficiency Hazard Safety: ODH Hazard Classification Signs.<sup>4</sup> Signs are available from either the cryogenic safety program manager or the confined space program manager.
2. A properly operating oxygen monitor must be used by persons participating in operations areas categorized as ODH 1 or greater. An installed monitor is by itself sufficient for ODH 1 areas, while for ODH 2 and higher areas the use of a personal monitor by all individuals is also required. Oxygen monitor units must be installed and set to provide a local O<sub>2</sub> readout and alarm with horn and light when the oxygen level falls below 19.5 percent.
3. The ventilation rate during occupancy should be at least one effective volume change per hour accomplished by any reliable means.

3 ES&H Course 170, Cryogenic and Oxygen Deficiency Safety Training, [https://www-internal.slac.stanford.edu/esh-db/training/slaonly/bin/catalog\\_item.asp?course=170](https://www-internal.slac.stanford.edu/esh-db/training/slaonly/bin/catalog_item.asp?course=170)

4 Cryogenic and Oxygen Deficiency Hazard Safety: ODH Hazard Classification Signs (SLAC-I-730-0A06S-003), <http://www-group.slac.stanford.edu/esh/eshmanual/references/cryogenicsODHSigns.pdf>

## Cryogenic and Oxygen Deficiency Hazard Safety: ODH Control Requirements

4. Relief valves and vent piping will be designed according to the following requirements:
  1. Reliefs cannot be vented into a building if they can release large quantities of gas due to normal operation, quench, operator error, freezing, or control system failure.
  2. Reliefs that require fracture of a solid pipe or fitting in order to release large quantities of gas may be vented into a building.
  3. Trapped volume reliefs that cannot vent a significant quantity of gas may vent into the building.

*Note* The design requirements assume there is a working oxygen monitoring system with loud local alarm and a ventilation system designed specific to the cryogenic hazards. In some locations, this may require a ventilation fan whose operation is controlled by installed oxygen monitors. The HEEC chairman must approve, in writing, the design of all control systems for new and modified cryogenic installations.

### **Personnel Controls/Routine Access**

The following practices are mandatory under the conditions indicated in Table 1 above:

1. Individuals who are required to enter ODH work areas on a routine basis must first complete ES&H Course 170, Cryogenic and Oxygen Deficiency Safety Training.<sup>5</sup>
2. Individuals working in any work area classified as ODH 2 or higher must be equipped with a personal oxygen monitor. Personal oxygen monitors for entry into ODH 2 areas are issued and maintained by the CEF Cryogenic Operations Group. Area oxygen monitors are sufficient in and of themselves for work areas classified as ODH 1.
3. More than one individual must be present at any one time in any work area classified as ODH 2, and all of these individuals must be appropriately qualified (two-person rule).
4. All personnel engaged in work activities in work areas classified as ODH 3 or 4 must be in continuous communication with an observer who is not physically present in the work area. The purpose of the observer is to summon help in the case of an ODH emergency (three-person rule).
5. Individuals must wear a self-contained breathing apparatus (SCBA) during any operation in an ODH 4 area. SLAC policy stipulates that the only individuals allowed into an ODH 4 area at SLAC will be Fire Department personnel. Annual training in SCBA use is required.
6. In addition to being trained in SCBA use, all Fire Department personnel must be designated as medically fit to wear and SCBA by the SLAC Medical Department.

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<sup>5</sup> ES&H Course 170, Cryogenic and Oxygen Deficiency Safety Training, [https://www-internal.slac.stanford.edu/esh-db/training/slaonly/bin/catalog\\_item.asp?course=170](https://www-internal.slac.stanford.edu/esh-db/training/slaonly/bin/catalog_item.asp?course=170)

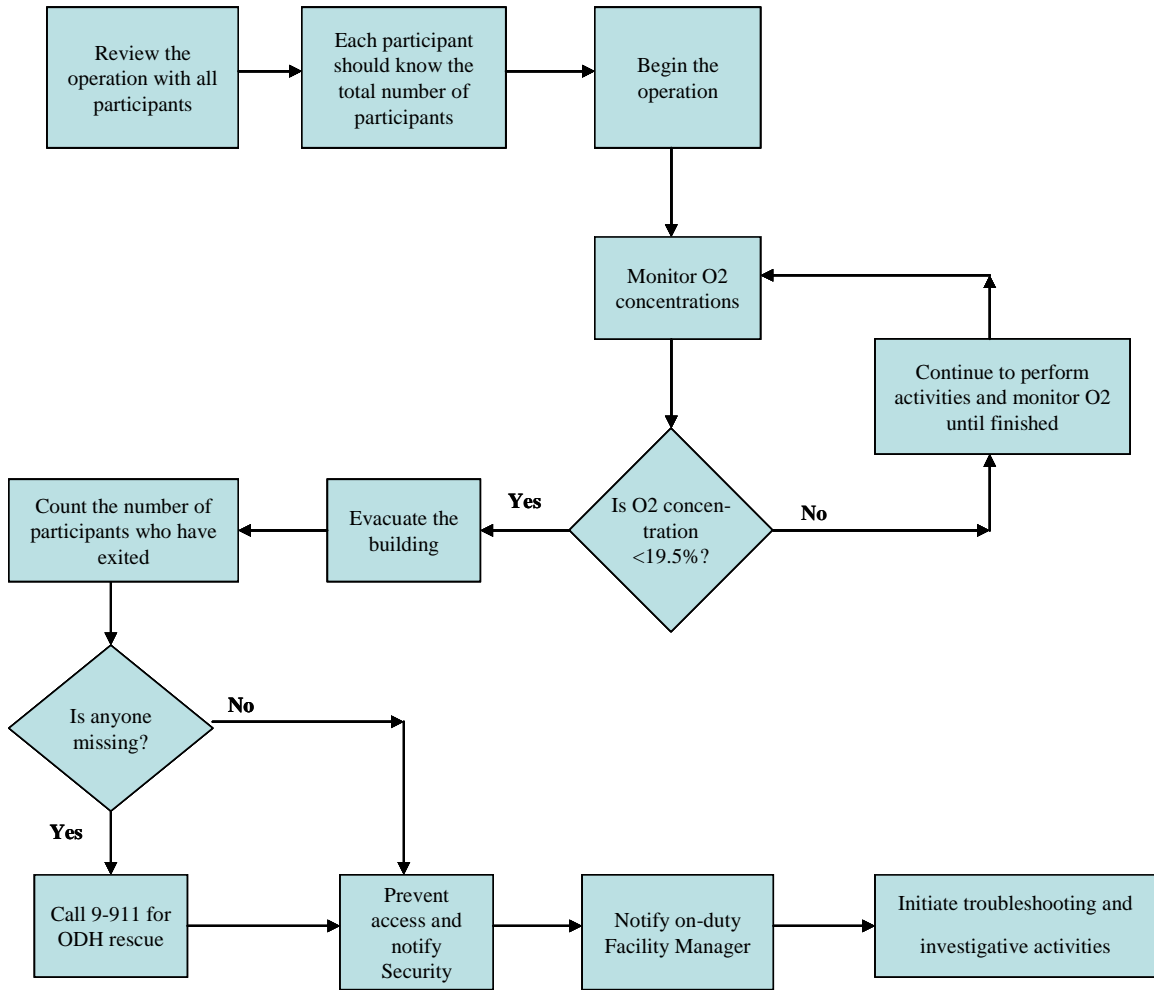
## Cryogenic and Oxygen Deficiency Hazard Safety: ODH Control Requirements

7. Before entering any ODH area at SLAC, an untrained visitor must be given an ODH hazard awareness briefing by either the cryogenic safety program manager or the confined space program manager.
8. Following the hazard awareness briefing, untrained visitors may enter ODH 0 area at SLAC without an escort. However, all entries of untrained visitors to ODH 1 areas will require a one-on-one escort by trained personnel. All entries of untrained visitors to ODH 2 and higher areas are forbidden.

### ODH Emergency Procedures

Emergency evacuation and rescue procedures for any ODH area must be conducted in accordance with the flow chart in Figure 1. Local facility/area plans may differ slightly from that shown here.

Figure 1 ODH Emergency Evacuation and Rescue Flow Chart





# Cryogenic and Oxygen Deficiency Hazard Safety: ODH Risk Assessment Procedures

Department: Field Safety and Building Inspection

Program: Cryogenic and Oxygen Deficiency Hazard Safety

Owner: Program Manager

Authority: ES&H Manual, Chapter 36, Cryogenic and Oxygen Deficiency Hazard Safety<sup>1</sup>

Below are relevant factors in an ODH risk assessment:

- Effects produced by reduced atmospheric oxygen
- Probability of equipment failure
- Probability of human error
- Reliability of safety and ventilation equipment

ODH classifications are based on estimated fatality rates in the absence of countermeasures.

An ODH risk assessment should include an evaluation of each of the following factors:

1. Significant potential sources of reduced atmospheric oxygen
2. Mechanisms for failure
  - Spontaneous failures
  - Personnel-mediated failures
  - Operator error
  - Accidents
3. Operations
  - Routine steady-state conditions
  - Other
    - Start-up
    - Repairs
    - Special operations
    - Shutdown
4. Gas dynamics
  - Ventilation
    - Natural
    - Forced
  - Stratification/mixing
  - Diffusion
5. The basis used for conclusion
6. Requirements

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1 *SLAC Environment, Safety, and Health Manual* (SLAC-I-720-0A29Z-001), Chapter 36, “Cryogenic and Oxygen Deficiency Hazard Safety”, [http://www-group.slac.stanford.edu/esh/hazardous\\_substances/cryogenic/policies.htm](http://www-group.slac.stanford.edu/esh/hazardous_substances/cryogenic/policies.htm)

# Cryogenic and Oxygen Deficiency Hazard Safety: ODH Risk Assessment Procedures

Department: Field Safety and Building Inspection

Program: Cryogenic and Oxygen Deficiency Hazard Safety

Owner: Program Manager

Authority: ES&H Manual, Chapter 36, Cryogenic and Oxygen Deficiency Hazard Safety<sup>1</sup>

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  - Personnel-mediated failures
  - Operator error
  - Accidents
3. Operations
  - Routine steady-state conditions
  - Other
    - Start-up
    - Repairs
    - Special operations
    - Shutdown
4. Gas dynamics
  - Ventilation
    - Natural
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  - Diffusion
5. The basis used for conclusion
6. Requirements

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1 *SLAC Environment, Safety, and Health Manual* (SLAC-I-720-0A29Z-001), Chapter 36, “Cryogenic and Oxygen Deficiency Hazard Safety”, [http://www-group.slac.stanford.edu/esh/hazardous\\_substances/cryogenic/policies.htm](http://www-group.slac.stanford.edu/esh/hazardous_substances/cryogenic/policies.htm)

- Area and personal oxygen monitors
- ODH controlled ventilation
- Self-rescue supplied-atmosphere respirators
- Special procedures

**Effects of Exposure to Reduced Atmospheric Oxygen**

Air normally contains about 21 percent diatomic oxygen (O<sub>2</sub>) with the remainder consisting mostly of nitrogen. Although this section is written in terms of percent O<sub>2</sub> at sea level, the preferred index of hazard is partial pressure of O<sub>2</sub>. Percent O<sub>2</sub> is used to maintain consistency with the readouts on oxygen monitors.

Individuals exposed to reduced-oxygen atmospheres may suffer a variety of harmful effects. A list of some of these physical effects and the sea-level oxygen concentrations at which the effects can occur is presented in Table 1. At higher altitudes, the same effects generally occur at greater volume concentrations as the partial pressure of oxygen is less.

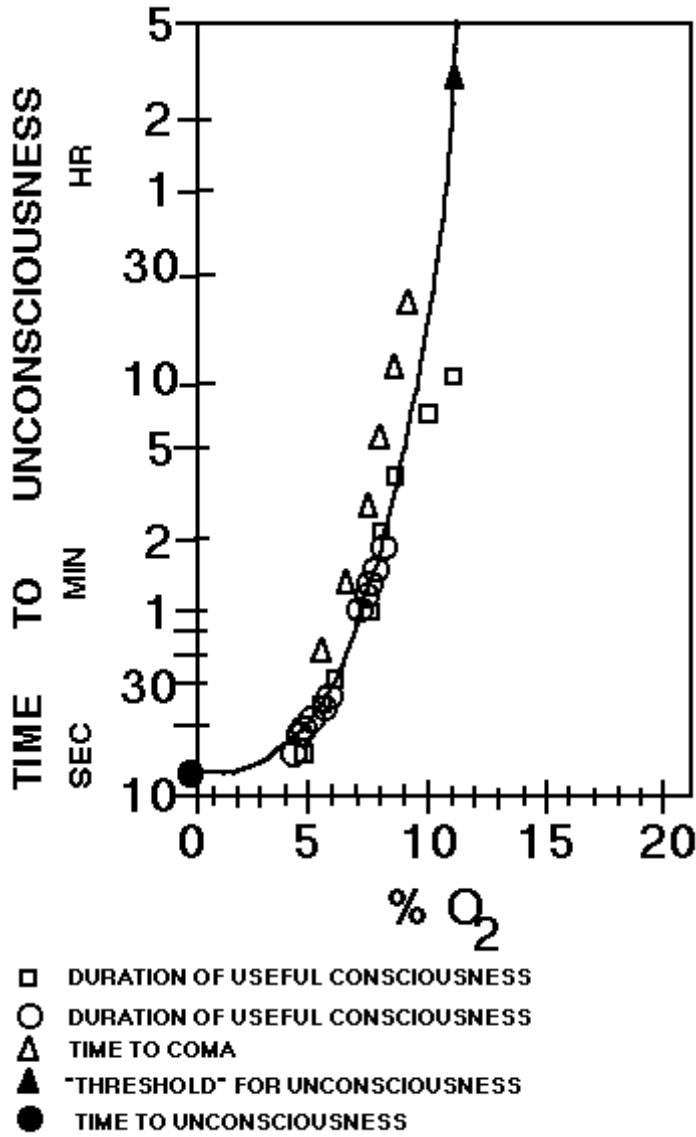
**Table 1** Effect Thresholds for Exposure to Reduced Oxygen

Volume % Oxygen	Effect
17	Night vision reduced Increased breathing volume Accelerated heartbeat
16	Dizziness Reaction time for novel tasks doubled
15	Impaired attention Impaired judgment Impaired coordination Intermittent breathing Rapid fatigue Loss of muscle control
12	Very faulty judgment Very poor muscular coordination Loss of consciousness Permanent brain damage
10	Inability to move Nausea Vomiting
6	Spasmodic breathing Convulsive movements Death in 5-8 minutes

If exposure to reduced oxygen is terminated early enough, effects are generally reversible. If not, permanent central nervous system damage or death can result. Disorientation and unconsciousness can hinder escape from the vicinity of an oxygen deficiency.

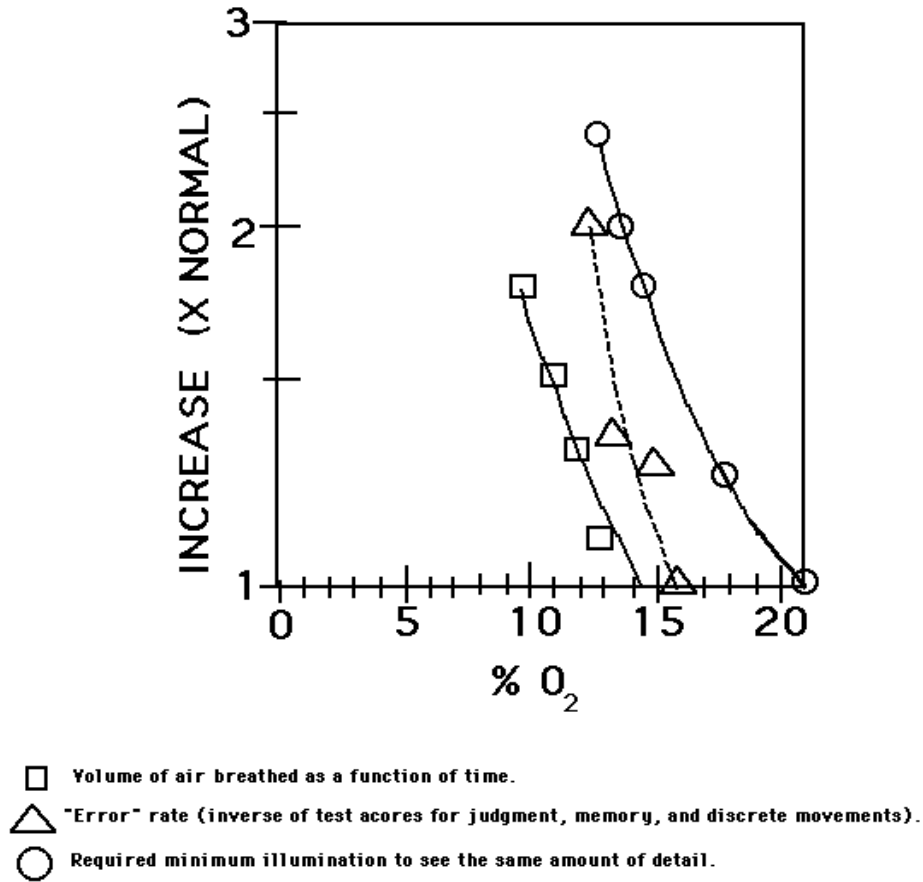
The time of useful consciousness against percent oxygen for seated individuals at sea level is shown in Figure 1. For active individuals, the threshold for unconsciousness is 13 percent.

Figure 1 Approximate time of useful consciousness as a function of oxygen concentration for seated subjects at sea level



The effect of oxygen deficiency on breathing, central nervous system error rates, and vision is shown in Figure 2.

Figure 2 Other effects as a function of oxygen concentration for seated subjects at sea level



In general, the effect intensity increases rapidly with lower oxygen concentration and longer exposure duration: first reduced abilities, then unconsciousness, then death. Any exposure to an atmosphere containing less than 17 percent oxygen presents a substantial health risk.

All oxygen monitoring in use at SLAC for the cryogen safety program, both permanently installed instrumentation and personnel monitors, is set to alarm at 19.5 percent. SLAC requires the immediate evacuation of all personnel from any ODH area when the measured O<sub>2</sub> concentration is 18 percent or less.

**Estimation of ODH Fatality Rate**

The goal of an ODH risk assessment is to estimate the rate increase in the occurrence of fatalities as a result of exposure to an oxygen-reduced atmosphere.

Since the level of risk is directly related to the nature of the operation, the excess fatality rate must be determined on an operation-by-operation basis. For a given operation, several events may cause an oxygen deficiency. Each event has an expected rate of occurrence and each occurrence has an expected probability of fatality. The ODH fatality rate is defined as:

$$\phi = \sum_{i=1}^n P_i F_i$$

where:

$\phi$  = the ODH fatality rate (per hour)

$P_i$  = the expected rate of the  $i$  type of event, (per hour)

$F_i$  = the fatality factor for the  $i$  type event.

The summation must include all types of events that may cause an ODH and result in a fatality. When possible, the value of  $P_i$  should be based on operating experience at SLAC; otherwise, data from similar systems elsewhere or other relevant values can be used.

**Estimation of Event Rates,  $P_i$**

Estimates of spontaneous equipment failure rates are provided in the two tables below. Table 2 contains median estimates collected from past ODH risk assessments conducted at Fermilab, while Table 3 lists values derived from systems used in the nuclear power industry. Information is presented either as a time rate (x/hr) or per demand rate (x/D).

Human error rate estimates are presented in Table 4 and Table 5.

Table 2 Fermilab Equipment Failure Rate Estimates

Failure Mode	Estimated Median Failure Rate	
Compressor (cryogenic)	Leak or rupture	3 x 10 <sup>-5</sup> /hr
Dewar	Leak or rupture	1 x 10 <sup>-6</sup> /hr
Unplanned electrical power failure	Time rate (Time off)	1 x 10 <sup>-4</sup> /hr (1 hr)
Fluid line (cryogenic)	Leak or rupture	3 x 10 <sup>-6</sup> /hr
Magnet (cryogenic)	Leak or rupture	1 x 10 <sup>-6</sup> /hr
U-tube change release (cryogenic)	Small Event	1 x 10 <sup>-3</sup> /hr
	Large Event	4 x 10 <sup>-5</sup> /hr

## Cryogenic and Oxygen Deficiency Hazard Safety: ODH Risk Assessment Procedures

**Table 3** NRC Equipment Failure Rate Estimates

Equipment	Failure Mode	Median Failure Rate
Batteries Power supplies	No output	3 x 10 <sup>-6</sup> /hr
Circuit breakers	Failure to operate Premature transfer	1 x 10 <sup>-3</sup> /hr 1 x 10 <sup>-6</sup> /hr
Diesel (complete plant) (emergency loads) Diesel (engine only)	Failure to start Failure to run Failure to run	3 x 10 <sup>-2</sup> /D 3 x 10 <sup>-3</sup> /hr 3 x 10 <sup>-4</sup> /hr
Electric Motors	Failure to start Failure to run Failure to run-extreme environment	3 x 10 <sup>-4</sup> /D 1 x 10 <sup>-5</sup> /hr 1 x 10 <sup>-3</sup> /hr
Fuses	Premature, open Failure to open	1 x 10 <sup>-6</sup> /hr 1 x 10 <sup>-5</sup> /hr
Gaskets	Leak	3 x 10 <sup>-6</sup> /hr
Flanges, Closures, Elbows	Leak/rupture	3 x 10 <sup>-7</sup> /hr
Instrumentation (amplification, annunciators, transducers, calibration, combination)	Failure to operate Shifts	1 x 10 <sup>-6</sup> /hr 3 x 10 <sup>-5</sup> /hr
Pipes > 3", high quality	Rupture (section)	1 x 10 <sup>-10</sup> /hr
Pipes < 3"	Rupture	1 x 10 <sup>-9</sup> /hr
Pumps	Failure to start Failure to run-normal Failure to run-extreme environment	1 x 10 <sup>-3</sup> /D 3 x 10 <sup>-5</sup> /hr 1 x 10 <sup>-3</sup> /hr
Relays	Failure to energize Failure-no contact to close Short Across NO/NC contact Open NC contact	1 x 10 <sup>-4</sup> /D 3 x 10 <sup>-7</sup> /hr 1 x 10 <sup>-8</sup> /hr 1 x 10 <sup>-7</sup> /hr
Solid State Devices	Fails to function Shorts	3 x 10 <sup>-6</sup> /hr 1 x 10 <sup>-6</sup> /hr
Hi Power Application Low Power Application	Fails to function Shorts	1 x 10 <sup>-6</sup> /hr 1 x 10 <sup>-7</sup> /hr
Switches	Limit: fail to operate Torque: fail to operate Pressure: fail to operate Manual: fail to operate Manual: contacts short	3 x 10 <sup>-4</sup> /D 1 x 10 <sup>-4</sup> /D 1 x 10 <sup>-4</sup> /D 1 x 10 <sup>-4</sup> /D 1 x 10 <sup>-8</sup> /hr
Transformers	Open Short	1 x 10 <sup>-6</sup> /hr 1 x 10 <sup>-6</sup> /hr
Manually operated valve	Fails to operate (plug) Failure to remain open External leak-rupture	1 x 10 <sup>-3</sup> /D 1 x 10 <sup>-4</sup> /D 1 x 10 <sup>-8</sup> /hr

## Cryogenic and Oxygen Deficiency Hazard Safety: ODH Risk Assessment Procedures

Equipment	Failure Mode	Median Failure Rate
Solenoid operated valve	Fails to operate	1 x 10 <sup>-3</sup> /D
Air operated valve	Fails to operate (plug) Failure to remain open External leak-rupture	3 x 10 <sup>-4</sup> /D 1 x 10 <sup>-4</sup> /D 1 x 10 <sup>-8</sup> /hr
Check valve	Failure to open Reverse leak External leak-rupture	1 x 10 <sup>-4</sup> /D 3 x 10 <sup>-7</sup> /hr 1 x 10 <sup>-8</sup> /hr
Vacuum valve	Failure to operate Rupture	3 x 10 <sup>-5</sup> /D 1 x 10 <sup>-8</sup> /hr
Valves: orifices, flow, meters, (test)	Rupture	1 x 10 <sup>-8</sup> /hr
Valves (relief)	Fail to open Premature open	1 x 10 <sup>-5</sup> /D 1 x 10 <sup>-5</sup> /hr
Welds	Leak	3 x 10 <sup>-9</sup> /hr

**Table 4** Human Error Rate Estimates

Estimate Error Rate per Demand	Activity
10 <sup>-3</sup>	Selection of a switch (or pair of switches) dissimilar in shape or location to the desired switch, assuming no decision error. For example, operator actuates large handled switch rather than small switch.
3 x 10 <sup>-3</sup>	General human error of commission, e.g., misreading label and therefore selecting wrong switch.
10 <sup>-2</sup>	General human error of omission where there is no display in the control room of the status of the item omitted, e.g., failure to return manually operated test valve to proper configuration after maintenance.
3 x 10 <sup>-3</sup>	Errors of omission, where the items being omitted are embedded in a procedure rather than at the end of a procedure as above.
1/x	Given that an operator is reaching for an incorrect switch (or pair of switches), he/she selects a particular similar appearing switch, where x = the number of incorrect switches adjacent to the desired switch. The 1/x applies up to 5 or 6 items. After that point the error rate would be lower because the operator would take more time to search. With up to 5 or 6 items he/she doesn't expect to be wrong and, therefore, is more likely to do less deliberate searching.
10 <sup>-1</sup>	Monitor or inspector fails to recognize initial error by operator. Note: With continuing feedback of the error on the annunciator panel, this high error rate would not apply.
10 <sup>-1</sup>	Personnel on different work shifts fail to check condition of hardware unless required by check or written directive.
5 x 10 <sup>-1</sup>	Monitor fails to detect undesired position of valves, etc., during general walk-around inspections, assuming no check list is used.
0.2–0.3	General error rate given very high stress levels where dangerous activities are occurring rapidly.
2 <sup>(n-1)</sup> x	Given severe time stress, as in trying to compensate for an error made in an

# Cryogenic and Oxygen Deficiency Hazard Safety: ODH Risk Assessment Procedures

Estimate Error Rate per Demand	Activity
	emergency situation, the initial rate, $x$ , for an activity doubles for each attempt, $n$ , after a previous incorrect attempt, until the limiting condition of an error rate of 1.0 is reached or until time runs out. This limiting condition corresponds to an individual's becoming completely disorganized or ineffective.

**Table 5** Human Error Rate as a Function of Response Time

Maximum Estimated Error Rate per Demand	Response Time (sec)		
	Skill-based Task <sup>1</sup>	Rule-based Task <sup>2</sup>	Knowledge-based Task <sup>3</sup>
$10^{-4}$	37	600	18,000
$10^{-3}$	26	300	10,000
$10^{-2}$	16	130	4,900
$10^{-1}$	8.7	42	1,800
$5 \times 10^{-1}$	4.0	10	550

*Notes:*

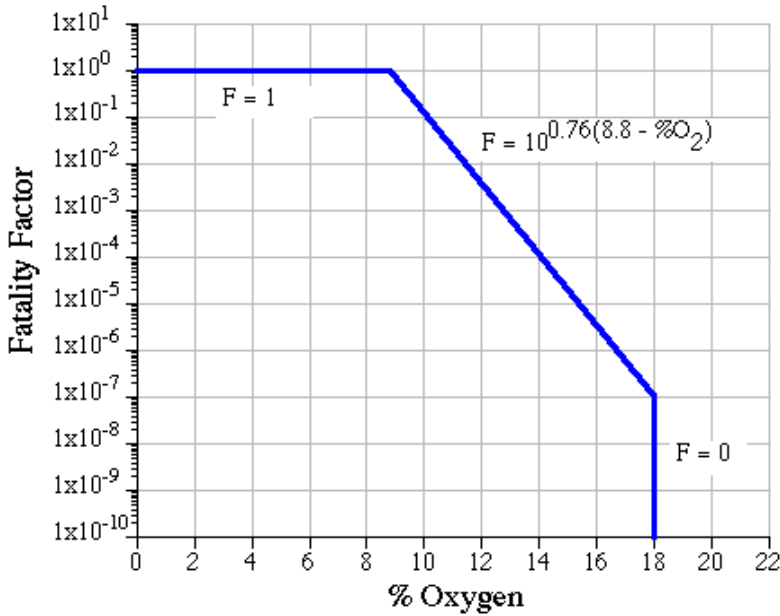
- 1 Skill-based task. An individual initiates a single-step learned response upon receipt of an unambiguous sensor cue. An example of a skill-based task would be when a lone worker initiates escape upon hearing an oxygen deficiency alarm.
- 2 Rule-based task. An individual or small group of individuals diagnoses and initiates corrective actions for a simple problem given limited or ambiguous input. Several workers deciding whether or not to escape given that one of them passes out but no oxygen deficiency alarm has sounded would be a rule-based task example.
- 3 Knowledge-based task. A group of individuals diagnoses and initiates corrective actions for a novel and/or complex problem.

## ***Estimation of the Fatality Factor, $F_i$***

The value of  $F_i$  is the probability that a person will die if the  $i$ th event occurs. This value depends on the oxygen concentration, the duration of exposure, and the difficulty of escape. For convenience of calculation, a relationship between the value of  $F_i$  and the lowest attainable oxygen concentration is displayed in Figure 3. The lowest concentration is used rather than an average as the minimum value is conservative and not enough is understood to allow the definition of an averaging period. If the lowest oxygen concentration is greater than 18 percent, then the value of  $F_i$  is zero. In other words, all exposures above 18 percent do not contribute to the fatality rate. The value of  $F_i$  is designed to reflect this threshold of oxygen concentration.

If the lowest attainable oxygen concentration is 18 percent, then the value of  $F_i$  is  $10^{-7}$ . This value would cause  $f$  to be  $10^{-7}$  per hour if the expected occurrence rate of the event was one per hour. As oxygen concentrations decrease, the value of  $F_i$  should increase until the probability of a fatality occurring is 1. That fatality point was defined as an oxygen concentration of 8.8 percent, which is the point at which one minute of consciousness is expected.

Figure 3 Fatality factor  $F_i$  versus the lowest attainable oxygen concentration which can result from a given event



### ODH Fatality Rate and ODH Classifications

Once the ODH fatality rate,  $\phi$ , without countermeasures has been determined, the operation can then be assigned an ODH classification according to the criteria outline in Table 6.

Table 6 Oxygen Deficiency Hazard Classification

ODH Class	$\phi$ ( $hr^{-1}$ )
0	$< 10^{-7}$
1	$> 10^{-7}$ but $< 10^{-5}$
2	$> 10^{-5}$ but $< 10^{-3}$
3	$> 10^{-3}$ but $< 10^{-1}$
4	$> 10^{-1}$



## **Cryogenic and Oxygen Deficiency Hazard Safety: ODH Hazard Classification Signs**

Department: Field Safety and Building Inspection

Program: Cryogenic and Oxygen Deficiency Hazard Safety

Owner: Program Manager

Authority: ES&H Manual, Chapter 36, Cryogenic and Oxygen Deficiency Hazard Safety<sup>1</sup>

See following pages for sign examples.

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<sup>1</sup> *SLAC Environment, Safety, and Health Manual* (SLAC-I-720-0A29Z-001), Chapter 36, “Cryogenic and Oxygen Deficiency Hazard Safety”, [http://www-group.slac.stanford.edu/esh/hazardous\\_substances/cryogenic/policies.htm](http://www-group.slac.stanford.edu/esh/hazardous_substances/cryogenic/policies.htm)

# ***NOTICE***

## **OXYGEN DEFICIENCY HAZARD**

# **0**

**PRIOR TO ENTRY ALL PERSONNEL MUST HAVE THE FOLLOWING:**

- **OXYGEN DEFICIENCY HAZARD TRAINING**



# CAUTION

**OXYGEN  
DEFICIENCY  
HAZARD**

**1**

**PRIOR TO ENTRY ALL PERSONNEL MUST HAVE THE FOLLOWING:**

- **OXYGEN DEFICIENCY HAZARD TRAINING**



# CAUTION

## OXYGEN DEFICIENCY HAZARD

# 2

**PRIOR TO ENTRY ALL PERSONNEL MUST HAVE THE FOLLOWING:**

- **PERSONAL OXYGEN MONITOR**
- **OXYGEN DEFICIENCY HAZARD TRAINING**

# DANGER

## OXYGEN DEFICIENCY HAZARD

# 3

**PRIOR TO ENTRY ALL PERSONNEL MUST HAVE THE FOLLOWING:**

- **MULTIPLE PERSONNEL IN CONTINUOUS COMMUNICATION (2<sup>nd</sup>/3<sup>rd</sup> person rules)**
- **PERSONAL OXYGEN MONITOR**
- **OXYGEN DEFICIENCY HAZARD TRAINING**

# **DANGER**

## **OXYGEN DEFICIENCY HAZARD**

# **4**

**PRIOR TO ENTRY ALL PERSONNEL MUST HAVE THE FOLLOWING:**

- **30-MINUTE SELF-CONTAINED BREATHING APPARATUS (SCBA)**
- **MEDICAL CLEARANCE FOR ODH WORK**
- **MULTIPLE PERSONNEL IN CONTINUOUS COMMUNICATION (2<sup>nd</sup>/3<sup>rd</sup> person rules)**
- **PERSONAL OXYGEN MONITOR**
- **OXYGEN DEFICIENCY HAZARD TRAINING**

# Cryogenic and Oxygen Deficiency Hazard Safety: Classified ODH Locations

Department: Field Safety and Building Inspection

Program: Cryogenic and Oxygen Deficiency Hazard Safety

Owner: Program Manager

Authority: ES&H Manual, Chapter 36, Cryogenic and Oxygen Deficiency Hazard Safety<sup>1</sup>

The following table lists current ODH classified locations. Note cryogenic work can temporarily alter the ODH classification of a work area. The cryogenic and oxygen deficiency hazard safety program manager directs such activities and is responsible for reclassification, subject to approval by the chair of HEEC.

ODH Classification	Building Name	Specific Area
ODH 0	All liquid nitrogen tanks	See site map for tank locations 1-6, 8, 9, 12-15
ODH 1	Building 750	Entire pit area
	SSRL	All hutches with ODH alarms
	Central Lab annex	OX experiment
	Glast	Major clean room Shipment receiving room
ODH 2	Building 127	Helium Compressor Room
	BaBar/IR-2	Liquifier Room
	Building 113	CTI 4000 Installation

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<sup>1</sup> *SLAC Environment, Safety, and Health Manual* (SLAC-I-720-0A29Z-001), Chapter 36, “Cryogenic and Oxygen Deficiency Hazard Safety”, [http://www-group.slac.stanford.edu/esh/hazardous\\_substances/cryogenic/policies.htm](http://www-group.slac.stanford.edu/esh/hazardous_substances/cryogenic/policies.htm)



# Cryogenic and Oxygen Deficiency Hazard Safety: Physical Properties of Common Cryogenes

Department: Field Safety and Building Inspection

Program: Cryogenic and Oxygen Deficiency Hazard Safety

Owner: Program Manager

Authority: ES&H Manual, Chapter 36, Cryogenic and Oxygen Deficiency Hazard Safety<sup>1</sup>

Element	Boiling Point (K)	Liquid-to-Gas Expansion Ratio	Gas Specific Density	Critical Temperature (K)	Critical Pressure (atm)	Liquid Density (g/L)
He	4.2	780	0.14	5.2	2.2	125
H <sub>2</sub>	20.3	865	0.07	33.0	12.8	71
Ne	27.1	1470	0.70	44.4	26.2	1206
N <sub>2</sub>	77.3	710	0.97	126.3	33.5	808
Ambient air	--	--	1.00	--	--	--
Ar	87.3	860	1.39	150.9	48.3	1,402
O <sub>2</sub>	90.2	875	1.11	154.8	50.1	1,410
CO <sub>2</sub>	194.7	790	1.70	304.2	72.8	1,560
R-12	243.4	294	4.35	385.0	40.6	1,487

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1 *SLAC Environment, Safety, and Health Manual* (SLAC-I-720-0A29Z-001), Chapter 36, "Cryogenic and Oxygen Deficiency Hazard Safety", [http://www-group.slac.stanford.edu/esh/hazardous\\_substances/cryogenic/policies.htm](http://www-group.slac.stanford.edu/esh/hazardous_substances/cryogenic/policies.htm)



# Cryogenic and Oxygen Deficiency Hazard Safety: General Guidelines

Department: Field Safety and Building Inspection

Program: Cryogenic and Oxygen Deficiency Hazard Safety

Owner: Program Manager

Authority: ES&H Manual, Chapter 36, Cryogenic and Oxygen Deficiency Hazard Safety<sup>1</sup>

Below are guidelines to prevent and respond to cryogenic hazards at SLAC.

- Be aware that small quantities of liquid nitrogen are used throughout SLAC and require careful handling procedures.
- Do not enter the following buildings without proper training and equipment:
  - Cryogenic Test Facility (Bldg 113 Low Bay)
  - Central Helium Facility (Bldg 127)
  - BaBar Helium Liquefier (IR2)
- In the event use of an elevator is necessary to transport a dewar (for example, in Central Lab, CEH, or SSRL elevators), do not travel in the elevator with the dewar; thus, transport will require the use of signage and multiple persons.
- Observe and follow instructions posted on ODH hazard classification signs and PPE signage at cryogen dispensing stations.
- Do not enter ODH areas unless trained for that area or escorted by ODH-trained staff qualified for that area.
- Leave the area immediately and notify your supervisor if
  - An oxygen deficiency warning light is illuminated
  - An oxygen deficiency alarm sounds – this is a loud stationary horn or a shrill whistle from a personal monitoring device.
- Be aware of the physical signs of an uncontrolled release of cryogenics:
  - A high-pressure cryogenic spill can drop temperatures to -244° F (120 K) within a 10-foot radius in a few seconds.
  - The presence of a water-vapor cloud, and in the case of high pressure, rushing gas sounds.
- Be aware of what to do in the case of an uncontrolled cryogen release:
  - Leave the area immediately.
  - Never exit the area through a vapor cloud.
  - If you find yourself in the path of a vapor cloud, hold your breath until you are out of the cloud.
  - If you see a vapor cloud moving toward you, exit away from the cloud.
- Do not attempt to rescue a downed worker during an ODH emergency. Any rescue attempts without proper training and equipment will only endanger yourself and the downed worker. Immediately call 911, then evacuate the area.
- In the event of a cold burn, first calm the victim and avoid aggravating the injury. If the feet are the part of the body with the burns, do not allow the victim to walk. Do

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1 *SLAC Environment, Safety, and Health Manual* (SLAC-I-720-0A29Z-001), Chapter 36, “Cryogenic and Oxygen Deficiency Hazard Safety”, [http://www-group.slac.stanford.edu/esh/hazardous\\_substances/cryogenic/policies.htm](http://www-group.slac.stanford.edu/esh/hazardous_substances/cryogenic/policies.htm)

## Cryogenic and Oxygen Deficiency Hazard Safety: General Guidelines

not rub, massage, or apply medications to affected areas. Immediately call 911. Remove the victim from the hazardous area to prevent further exposure. Remove any wet clothing. Cover affected body parts with a clean dry dressing and keep the victim warm.

# Cryogenic and Oxygen Deficiency Hazard Safety: Personal Protective Equipment Requirements

Department: Field Safety and Building Inspection

Program: Cryogenic and Oxygen Deficiency Hazard Safety

Owner: Program Manager

Authority: ES&H Manual, Chapter 36, Cryogenic and Oxygen Deficiency Hazard Safety<sup>1</sup>

Eye, hand, and body protection are necessary to prevent potential cold burns when handling cryogenics.

Eye protection is required at all times when handling cryogenic fluids. When pouring a cryogen or when working with a wide-mouth dewar (that is, open flow delivery), goggles or a full-face shield over safety glasses must be used. A face shield by itself does not provide adequate splash protection; safety glasses or goggles must be worn underneath as well. The only exceptions are for transporting cryogenics in closed dewars or portable tanks and disposing of very small quantities (less than 0.5 liter) by evaporation.

For hand protection, it is best to wear loose insulating gloves, which can be tossed off readily if they become soaked with cryogenics. For tasks requiring a high degree of dexterity that are difficult or impossible to perform while wearing insulating gloves, such as manipulating samples in small cryovials, a better solution is the use of insulated hand tools.

Never use clean room gloves which are absorbent (cotton) or porous (nylon) for hand protection.

Recommended body protection when working with large quantities of cryogenic fluids includes

- Cuff-less trousers extended over work boots
- Leather apron

SSRL has developed excellent solutions to PPE signage and storage of cryogen handling equipment, specifically at its LN<sub>2</sub> fill station inside B120 and at two of its cryovial handling locations. A link to examples of these solutions will be provided within one month of the publication of this chapter. Other work groups responsible for handling cryogenics at SLAC that are looking for guidance and solutions in this area would do well by appropriating the SSRL approach.

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1 *SLAC Environment, Safety, and Health Manual* (SLAC-I-720-0A29Z-001), Chapter 36, "Cryogenic and Oxygen Deficiency Hazard Safety", [http://www-group.slac.stanford.edu/esh/hazardous\\_substances/cryogenic/policies.htm](http://www-group.slac.stanford.edu/esh/hazardous_substances/cryogenic/policies.htm)