SLAC NATIONAL ACCELERATOR LABORATORY

ENVIRONMENT, SAFETY & HEALTH DIVISION

Chapter 36: Cryogenic and Oxygen Deficiency Hazard Safety

ODH Requirements

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1 Purpose

The purpose of these requirements is to protect workers from the *oxygen deficiency hazard (ODH)* associated with working with oxygen-displacing gases. They cover the introduction and use of oxygen-displacing gases, including cryogens, in work areas. They apply to workers, supervisors, responsible persons, ESH coordinators, and the cryogenic and oxygen deficiency hazard safety program manager.

The following hazards and controls are general to oxygen-displacing gases. For hazards and controls specific to cryogens, see Cryogenic and Oxygen Deficiency Hazard Safety: Cryogenic Requirements.

1.1 Hazards

An *oxygen deficiency hazard (ODH)* exists when the concentration of oxygen is 19.5 percent or less by volume at a nominal barometric pressure of 760 mm Hg (SLAC's elevation is about 300 feet, corresponding to a nominal barometric pressure of 752 mm Hg). Individuals exposed to reduced oxygen atmospheres may suffer a variety of harmful effects. Potential consequences increase as the oxygen levels decline. When oxygen levels drop into single digits, a person can lose consciousness in a few seconds and die of asphyxiation in a few minutes. At sufficiently low levels of oxygen there is no warning sign before unconsciousness, so it is especially important to be aware of potential hazards before beginning work in a potentially oxygen-deficient area (see Table 1).

Liquefied gases can easily and quickly create an ODH. When expelled to the atmosphere at room temperature, liquefied gases evaporate and expand 700 to 900 times their liquid volume. Consequently, leaks of even small quantities of liquefied gas can displace large amounts of oxygen-containing air, and render an atmosphere lethal.

Dense gases (those with densities significantly greater the atmospheric air) will fill pits and other low areas. Examples of dense gases include various freons, sulfur hexafluoride, and certain cold cryogens. Dense vapors will not readily mix with air and can "layer" and accumulate in depressions.

Air dense gases (those with densities approximating atmospheric air) are 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. One activity where this hazard is present is in many laboratories where continuous flow nitrogen is used as a vacuum system purge. Failure of the HVAC system normally in use in such locations (due to maintenance shutdown or power outage) can result in accumulation of inert gas sufficient to create a hazard, even without any failure of any part of the gas handling system. Also, cryogen spills out-of-doors can also result in localized ODH if there is insufficient air movement to dissipate the vapor.

Light gases (those with densities significantly lesser than atmospheric air) can affect the areas above a cryogen spill. Examples of light gases include helium and hydrogen. Experience has shown that with a connecting shaft of only a few square inches, an ODH condition can be present in spaces above the release location.

Users of oxygen-displacing gases should always be aware of the possibility that localized ODH conditions can exist. For example,

- Welding purge gas can accumulate behind the welder's helmet, creating an oxygen deficiency in the breathing space.
- Continuously flowing inert gas can accumulate underneath a fabric shroud on a laser table.

Table 1 Effects of Oxygen Deficiency by Volume

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	Spasmatic breathing Convulsive movements Death in 5-8 minutes

2 Requirements

2.1 Hazard Assessment

Before introducing oxygen-displacing gases, including cryogens, into a work area or changing the existing use of such gases (for example, by adding or modifying systems, changing operations, or changing the quantity of gases used), a quantitative, documented safety review must be performed by the responsible person, reviewed by his or her ESH coordinator, and approved by the cryogenic and oxygen deficiency hazard safety program manager. This safety review consists of an initial preliminary calculation of the oxygen level after a complete release of all cryogens and oxygen-displacing gases (at room temperature and pressure) into the room. If the resulting calculated oxygen level is less than 18 percent, a detailed risk assessment is required.

Note *There is a de minimis exemption from this requirement where the work area has at least one air change per hour of fresh air ventilation and an open floor plan for uses involving 1) a lecture bottle of compressed inert gas per 1,000 cubic feet of open lab space; 2) a standard K-bottle (200–300 cubic feet) of compressed inert gas per 3,000 cubic feet of open lab space; or 3) two liters of liquid nitrogen per 1,000 cubic feet of open lab space. Multiple, individual, bottles listed above are acceptable providing they are not connected together in a common system.*

The risk assessment results in a calculated risk of fatality from the ODH. Based upon the calculated fatality risk, an ODH hazard classification from ODH 0 to ODH 4 (see below) is assigned that is then used to determine required controls. The review must be completed and controls implemented before operations begin. (See Cryogenic and Oxygen Deficiency Hazard Safety: ODH Safety Review Procedure.)

2.2 Hazard Classification

All work areas in which cryogens or other oxygen-displacing gases are stored and/or used will be classified as follows.

- ODH 0. Hazard classification for areas with an estimated ODH fatality risk of less than 10^{-7} per hour
- ODH 1. Hazard classification for areas with an estimated ODH fatality risk of 10^{-7} to 10^{-5} per hour
- ODH 2. Hazard classification for areas with an ODH fatality risk of 10^{-5} to 10^{-3} per hour
- ODH 3. Hazard classification for areas with an ODH fatality risk of 10^{-3} to 10^{-1} per hour
- ODH 4. Hazard classification for areas with an ODH fatality risk of greater than 10^{-1} per hour

2.3 Controls

When ODH fatality risk exceeds 10^{-7} per hour (ODH 0), controls must be used to reduce the risk to as low as feasible. The minimum control measures required for each ODH classification are shown in Table 2. 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

Control requirements tailored to the ODH hazard classification of the work area and any engineering controls specified by the pre-operating approval must be implemented before starting operations.

Table 2 Minimum Required Controls by ODH Classification

ODH Classification	0[3]	1	2	3	4
Environmental and Engineering Controls					
1. Warning signs		X	X	X	X
1. Installed oxygen monitor		X	X	X	X
2. Ventilation		X	X	X	N/A
3. Relief valves and piping arrangements	As required by Chapter 14, “Pressure Systems”, or the cryogenic and ODH safety program manager				
Personnel Controls					
Routine					
4. ESH Course 170, Cryogenic and Oxygen Deficiency Safety Training		X	X	X	X
5. Personal oxygen monitor			X	X	X
6. Multiple-person team (two-person rule)[1]			X	X	X
7. Unexposed observer (three-person rule)[2]				X	X
8. Self-contained breathing apparatus					X
9. Medical approval as SCBA-qualified					X
Non-routine / visitors					
10. ODH hazard awareness briefing for visitors		X	X	N/A	N/A
11. One-to-one escort by ODH trained personnel			X	N/A	N/A

1 More than one individual must be present at any one time in any work area classified as ODH 2 or higher, and all of these individuals must be appropriately qualified (two-person rule) and within line-of-sight communication with each other.

2 All personnel working in 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). Remote monitoring via surveillance camera and communication via walkie-talkies is acceptable.

3. No placarding or training requirements are triggered by a classification of ODH 0.

2.3.1 Environmental and Engineering Controls

2.3.1.1 Signs

Appropriate ODH warning signs, specific to the ODH classification, must be posted at all entrances of ODH 1 or higher work areas. (See Figure 1 for examples.) Contact the program manager to obtain signs.

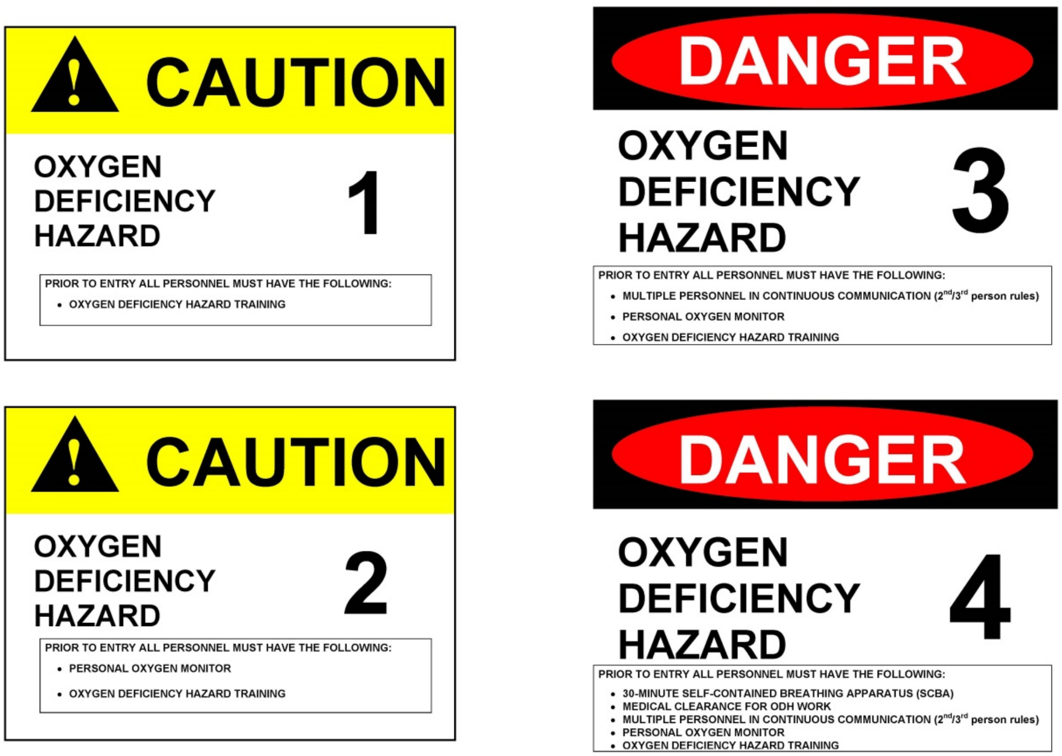

Figure 1 Sample ODH Signs

2.3.1.2 Oxygen Deficiency Monitors

A properly operating oxygen deficiency 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 each individual is also required. Monitors and alarm readouts must be placed so that they can be read and operated from outside of the potential ODH area. Oxygen deficiency monitor units must provide an oxygen readout and a local audible and visible alarm when the oxygen level falls below 19.5 percent. All installed ODMs must be registered with the cryogenic and ODH safety program manager. Oxygen deficiency monitors must be maintained according to the specifications of their manufacturer, and calibrated according to requirements of the Measuring and Test Equipment (M&TE) Calibration Program.

Figure 2 Non-personal oxygen deficiency monitor

2.3.1.3 Ventilation

The minimum ventilation rate during occupancy must be established during the ODH safety review. This may be accomplished by any reliable means.

2.3.1.4 Pressure Relief Devices and Vent Piping

Pressure relief devices e and vent piping are designed according to the following requirements and others as dictated by Chapter 14, "Pressure Systems":

- Generally, relief device that may vent a quantity of gas large enough to reduce the oxygen concentration to < 19.5 percent inside of the space due to normal operation, quench, operator error, freezing, or control system failure should be exhausted to a safe location outside of the building.
- Trapped volume reliefs that cannot vent a quantity of gas large enough to reduce the oxygen concentration to < 19.5 percent inside of the space may be vented into the building.
- In some cases, a supplemental relief device, such as a burst disc, may be permitted to vent into a building, irrespective of the volume of gas it can release. The risk assessment of the cryogenic system and space shall account for each failure mechanism and associated risk to determine the correct ODH classification.

2.3.1.5 Optional Controls for Consideration

Restrictive Flow Orifices

In certain situations, restrictive flow orifices in oxygen-displacing gas supply lines, solenoid valves in gas or cryogenic fluid delivery lines interfaced with the local ventilation supplies, and other engineered solutions are preferable to an oxygen deficiency monitor that reacts to an ODH situation.

A *restrictive flow orifice (RFO)* is a passive device that limits the uncontrolled flow from a compressed gas source. While not designed to be a modulator or control valve, an RFO will substantially reduce the flow rate under a specific set of pressure and temperature conditions for a given gas. An RFO has no moving parts and can be inserted into a plumbed compressed gas line outside of a laboratory to reduce the flow of oxygen-displacing gas into the room. RFOs can also be used with compressed gas cylinders. A good rule in properly sizing an RFO is to choose an RFO diameter that permits a flow rate two or three times above the flow rate desired in current applications to allow flexibility in future operations.

Flow Interlocks

Flow interlocks are used to either prevent entry or shut off gas or cryogen flow when undesired operating conditions exist. Examples include the following:

- HVAC interlocked with a (fail-closed) solenoid valve located in the supply line of oxygen-displacing gas or liquid cryogen. Once the volumetric flow rate of supplied air within the duct drops below a set point, a signal is sent from the differential pressure switch to a solenoid valve in the supply line to shut off the flow of gas or cryogenic liquid.
- A fixed oxygen deficiency monitor alarm interlocked in a feedback loop to the supply valve and shuts off the flow of gas in the system if the oxygen level in the room is below a set point.

Each cryogenic system is unique and the use of interlocks should be considered whenever feasible based on the inherent value of preventing accidents as opposed to mitigating their effects.

Controls for Stratification of Oxygen-displacing Gases

The physical properties of oxygen-displacing gases must be taken into consideration when designing appropriate hazard controls configurations. For example, if large volumes of helium are used as a cryogen in an accelerator tunnel then oxygen sensors need to be located where the gas would tend to accumulate during a release. Fixed oxygen monitors sensors should be located at ceiling height because helium is lighter than air.

Lintels and helium removal systems are engineering controls to be considered if large volumes of helium are used in underground tunnels. The lintels should be located to control helium from entering the exit paths, which allows sufficient time for staff to evacuate safely. (See Figure 3 below for an example.)

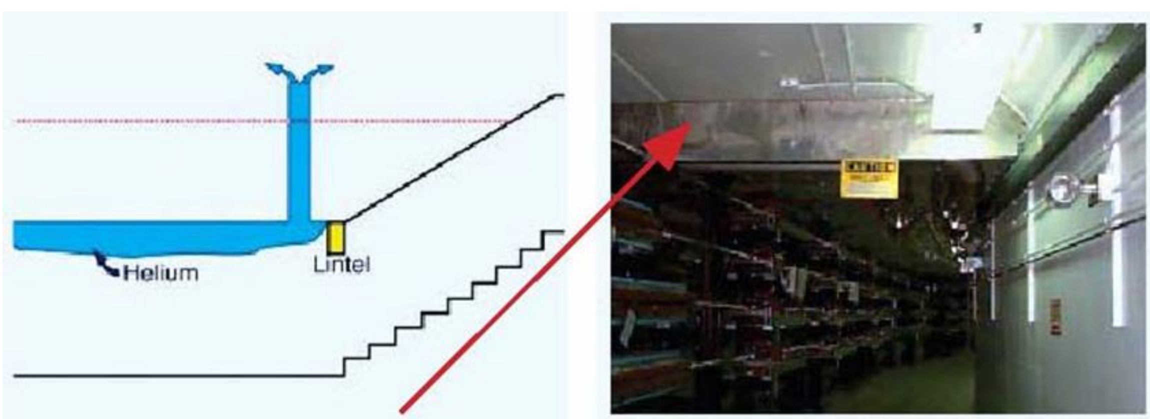

Figure 3 Lintel configuration at Thomas Jefferson National Laboratory

Service buildings located above such a tunnel that have ceiling to floor penetrations connecting an accelerator tunnel to service buildings require special attention to prevent an ODH situation in the above-ground buildings. Such penetrations must be identified and plugged to keep helium out of these buildings. Temporary changes in the ODH classification created by maintenance or shutdown work that displaces these plugs requires the reposting of the service buildings to a higher ODH classification during the work.

2.3.2 Personnel Controls

The following practices are mandatory under the conditions indicated in Table 2 above:

1. Individuals who are required to enter ODH 1 or higher work areas on a routine basis must first complete ESH Course 170, Cryogenic and Oxygen Deficiency Safety Training (ESH Course 170).
2. Individuals working in any work area classified as ODH 2 or higher must be equipped with a personal oxygen monitor. 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*) and within line-of-sight communication with each other.
4. All personnel working in 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*). Remote monitoring via surveillance camera and communication via walkie-talkies is acceptable.
5. Individuals must wear a *self-contained breathing apparatus (SCBA)* during any operation in an ODH 4 area. The only individuals allowed into an ODH 4 area at SLAC will be emergency responders.
6. Before entering any ODH 1 or higher area, an untrained visitor must be given an ODH hazard awareness briefing by the responsible person of the classified area.
7. Following the hazard awareness briefing, untrained visitors may enter ODH 1 areas without an escort. However, all entries of untrained visitors to ODH 2 areas will require a one-on-one escort within defined boundaries by trained personnel if permitted by approved ODH risk assessment. All entries of untrained visitors to ODH 3 and higher areas are forbidden.

2.3.3 Emergency Controls

2.3.3.1 Response to an Oxygen Deficiency Monitor Alarm

If an oxygen deficiency monitor alarm sounds

1. Immediately evacuate the ODH area
2. Do not re-enter the area until
   - The reason for the ODH alarm has been determined and corrected and
   - The oxygen deficiency monitor reads atmospheric oxygen greater than 19.5 percent.
3. Never attempt to reenter an ODH area while an alarm is sounding, even to rescue someone. All rescues must be carried out by properly equipped and trained emergency responders.
4. In all cases, never enter a space while the oxygen deficiency monitor alarm is indicating a hazard or malfunction condition. Refer to local ODM placard for definition of ODM status indicators and respond accordingly.

3 Forms

The following are forms required by these requirements:

- None

4 Recordkeeping

The following recordkeeping requirements apply for these requirements:

- None

5 References

SLAC Environment, Safety, and Health Manual (SLAC-I-720-0A29Z-001)

- Chapter 36, "Cryogenic and Oxygen Deficiency Hazard Safety"
  - Cryogenic and Oxygen Deficiency Hazard Safety: ODH Safety Review Procedure (SLAC-I-730-0A06C-001)
  - Cryogenic and Oxygen Deficiency Hazard Safety: Cryogenic Requirements (SLAC-I-730-0A06S-008)
- Chapter 14, "Pressure Systems"

Other SLAC Documents

- ESH Course 170, Cryogenic and Oxygen Deficiency Safety Training (ESH Course 170)
- Measuring and Test Equipment (M&TE) Calibration Program (SLAC-I-701-703-001-00)

Other Documents

- None