

Oxygen Deficiency Hazard

Safety Booklet



Central Helium Liquefier Complex

Many work areas at Jefferson Lab store or use compressed gasses, liquefied gasses, and volatile liquids. The uncontrolled release of these gasses and liquids could lead to a reduction in the amount of available oxygen in the work area. There are serious health effects associated with exposure to decreased oxygen levels. If oxygen levels drop significantly, unconsciousness or even death may occur.

This booklet provides information on how to recognize and protect yourself from cryogenic hazards. It also explains control measures used at Jefferson Lab to reduce these hazards. After reading this booklet, you should be able to work safely in Oxygen Deficiency Hazard (ODH) 0 and ODH 1 areas. In order to qualify as an ODH 0/1 worker, you must also pass the ODH proficiency test.

The Jefferson Lab Cryogenic Safety Chapter in the EH&S Manual serves as a companion for this booklet and should be consulted for more detailed information. You may also contact your supervisor and Division EHS staff with any questions you may have after reading this booklet.

Worker Requirements for Entry into ODH 0 and 1 Areas

Any personnel who need to enter ODH 0 and 1 areas without a qualified escort must either attend ODH training or pass the ODH proficiency test once every two years.

Visitor Requirements

Visitors who have not had ODH training may enter an ODH 0 or 1 area ONLY after the ODH hazard has been explained to them. An ODH qualified escort is required for visitor entry into ODH 1 areas.

Requirements for Tours

In order to conduct a tour of ODH areas, the tour leader must follow the requirements of a Temporary Operational Safety Procedure (TOSP) or an Operational Safety Procedure (OSP). Read the TOSP or OSP to see if the buddy rule applies for escorts. A copy of the OSP is available in the Safety Lab.

Keep this booklet in a convenient location for on-the-job reference.

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Questions or Comments?
Speak to any Safety Lab Staff
or Call ext. 7039

Hazards of Cryogenics & Mitigation

The principle hazards of cryogenics at Jefferson Lab are (in increasing order):

1. Risk of explosion: exposure to effects of flying debris and shrapnel caused by over-pressurization of a cryogenic device.
2. Risk of cryogenic burns to skin and eyes while dispensing cryogenics.
3. Oxygen Deficiency Hazard (ODH).

Mitigation of Cryogenic Hazards

1. Risk of explosion:

In order to mitigate the risk of explosion, careful engineering design is required. Critical considerations include the selection of suitable materials for cryogenic fabrications, and the installation of appropriate pressure relief devices in any volume that could become isolated in the system (for example by valve closures).

The design of experimental apparatus may include cryogenic devices. Examples include but are not limited to connection to dewars, feeds of cryogenic fluids to vacuum vessels. **Any such design requires the review and approval of a cryogenic expert.** When planning the use of such apparatus, contact the Cryogenic Coordinator, who then must document the approval the design drawings, the fabrication materials, and any associated safety equipment such as pressure relief devices.

2. Personal Protective Equipment (PPE):

- ✕ For dispensing cryogenics required personal protective equipment required includes :
- Eye protection: safety glasses and face shield; goggles for amounts under 1 liter
 - Hand protection: loose-fitting insulating cryogenic use gloves
 - Body protection: long pants, no open toed shoes.

3. Oxygen Deficiency Hazards (ODH)

The appropriate mitigation of the oxygen deficiency hazard associated with cryogen transport and use is achieved by a combination of engineering, administrative, and personal protective equipment controls. The discussion of the use of cryogenics and ODH Controls constitutes the remainder of this booklet.

NORMAL
vs.
OXYGEN DEFICIENT ATMOSPHERE

Normal Atmosphere

GAS	VOLUME
nitrogen	78%
oxygen	21%
argon/other	1%
TOTAL	100%


JEFFERSON LAB POLICY

19.5% Oxygen atmosphere is considered
to be hazardous Oxygen Deficient Atmosphere.


**Personnel WILL NOT enter or occupy an area in which the
oxygen concentration is less than 19.5%.**


Health Effects of Reduced Oxygen

Normal air is approximately 21% oxygen and 78% nitrogen. The remaining 1% is mostly argon. Health effects begin at an oxygen concentration of 17%. Oxygen monitors at Jefferson Lab are set to alarm at 19.5%. This advance warning should give ample time to escape the hazard area. The early health effects are difficult to detect so the oxygen monitors are relied upon to give early warning:



Percent Oxygen	Health Effects
17	Night vision reduced Increased breathing volume Accelerated heartbeat
16	Dizziness Reaction time for new tasks is doubled
15	Poor judgment Poor coordination Abnormal fatigue upon exertion Loss of muscle control
10-12	Very faulty judgment Very poor muscular coordination Loss of consciousness
8-10	Nausea Vomiting Coma
<8	Permanent brain damage
<6	Spasmodic breathing Convulsive movements Death in 5-8 minutes

 **NOTE:** Individuals with lung disorders or other health problems may experience health effects sooner than healthy individuals.

 **CAUTION:** Oxygen levels of less than 12% can cause unconsciousness suddenly and without warning: In such a low oxygen concentration the lungs see the environment as oxygen poor and will actually give up oxygen rather than take it in. Do not assume that if you are in an oxygen deficient atmosphere that you will be all right if you take a deep breath and hold it.

Oxygen Deficiency at Jefferson Lab: The Cryogen Connection

Oxygen deficiency hazards at Jefferson Lab are associated with standard industrial work, including the use of inert gases and refrigerants. However, the most significant oxygen deficiency hazard is associated with the use of the cryogens helium and nitrogen.


Properties of Cryogens


The term cryogenic is applied to very cold temperatures. Cryogenic fluids are extremely cold when in a liquid state. At normal temperatures they are gases. Gases used at Jefferson Lab that can exist as cryogens are: helium, nitrogen, argon, and hydrogen. The temperature of the liquid helium used to cool the accelerator cavities is 2 Kelvin. This equates to about -456°F .

Note: The cryogens used at Jefferson Lab are colorless. The white/grey cloud observed when a liquid cryogen evaporates to gas is water condensing from the atmosphere and is called the plume. The plume serves as a visual warning that a cryogenic gas is present. Note that plumes will not be visible when the gas warms up.

All cryogens expand when evaporating from liquid to gas. The expansion ratio can be estimated at 1000:1. This means that when a gallon of liquid cryogen evaporates 1,000 gallons of gas will form. When there is a release of liquid the liquid will evaporate rapidly and the percentage of other gases, most notably oxygen, will decrease in the area of the release. This high expansion ratio is the cause of the oxygen deficiency hazard.

Cryogens expand greatly. In the event of a release they can displace breathing air. Leaks in small spaces can also reduce oxygen levels over time.

 **NOTE: The cryogens used at Jefferson Lab are odorless and tasteless. Because we cannot sense them, their presence is monitored by the use of oxygen monitors. When a cryogen is released it will displace air as it rapidly evaporates and expands. The oxygen monitors will alarm when oxygen concentration drops to 19.5%**

 **NOTE: Wear loose fitting non-absorbent gloves so that in the event that the gloves are wetted with liquid they can be easily removed.**

↳ also need eye protection. See p. 4.

Whether cryogenic gases are lighter or heavier than air depends on gas density. This is important in determining where a released cryogen will accumulate. For example: monitors are at floor level to detect cryogenic plumes heavier than air and near the ceiling to detect cryogenic plumes lighter than air .

GAS	TEMPERATURE	LIGHTER OR HEAVIER THAN AIR	MONITOR PLACEMENT
helium	any	lighter	ceiling
nitrogen	cold	heavier	floor
	warm	lighter	ceiling
argon	any	heavier	floor
hydrogen	any	lighter	***

***Hydrogen is a flammable cryogen. The flammability hazard is more important than the oxygen deficiency hazard and becomes significant at low concentrations, so flammable gas detectors would be installed at ceiling level instead of oxygen monitors.

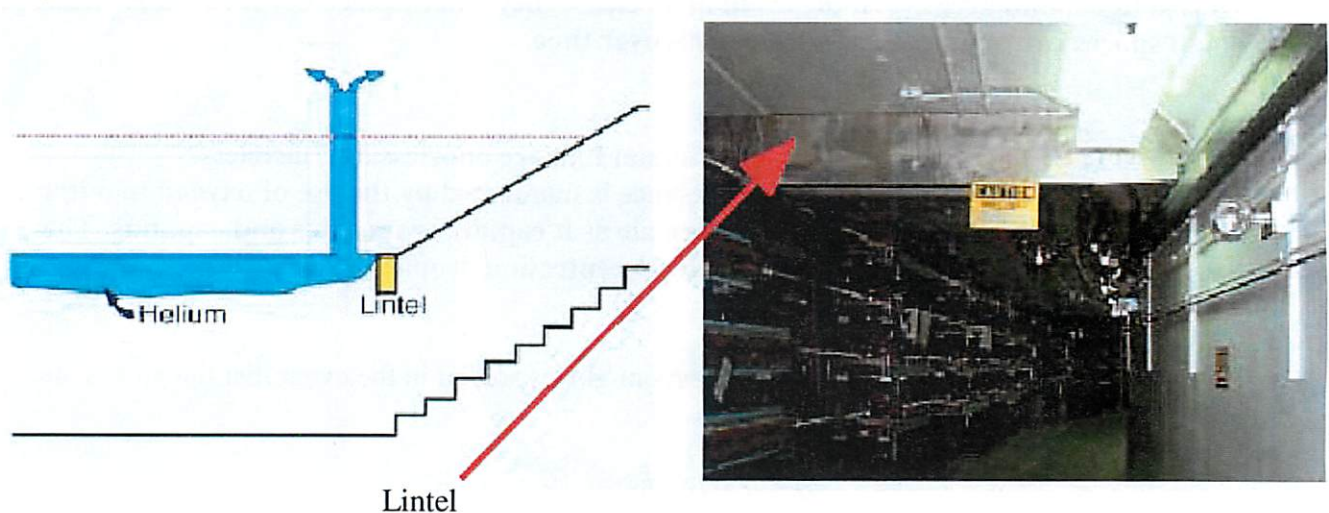
Cryogenic Support for the Accelerator

The cryogenic systems at Jefferson Lab use nitrogen and helium. (Argon and hydrogen are also on-site but are not used in the cryogenic refrigeration system for the accelerator.)

Accelerator


Helium is used as the cryogen in the Accelerator Tunnel to cool the superconducting cavities. Fixed oxygen monitors are located at ceiling height because helium is lighter than air

Lintels and helium removal systems are engineering controls installed in the tunnel. The lintels are located to keep helium from entering the exit stairwells for enough time for staff to evacuate safely.



Service Buildings

Service Buildings are located above the Accelerator, and penetrations connect the Accelerator Tunnel to the Service Buildings. All penetrations are plugged to keep helium out of these buildings.


 NOTE: Penetrations have been plugged in most Service Buildings associated with the Accelerator. This has reduced the hazard from ODH 1 to ODH 0 in the Service Buildings. Be aware that opening a plugged penetration will significantly increase the oxygen deficiency hazard in that localized area. Opening penetrations always requires RADCON notification and posting of the affected area as ODH1.

End Stations

Significant quantities of both helium and nitrogen are used in the end stations. Lesser amounts of hydrogen are also used. Fixed oxygen monitors are located near both the ceiling and the floor because helium is lighter than air and will rise while cold nitrogen is heavier than air and will sink. Very small amounts of liquid hydrogen may be used as cryogenic targets in the end stations. Hydrogen is not only a cryogen in its liquid state, but it is also a very flammable liquid and gas.

Free Electron Laser (FEL) Building

Helium is used as the cryogen in the FEL, lower level. Penetrations connect the lower level to the upper level, where electrical relay racks are located. Helium can rise through these penetrations, so the hazard level is significant in electrical relay racks located above open penetrations in the FEL upper level.

 NOTE: The presences of ambient temperature gas supplies, such as nitrogen and sulfur hexafluoride, also contribute to the oxygen deficiency hazard in the FEL.



Typical relay rack

Other ODH Cryogens

Liquid argon may be used by experimenters and welders and will be found in dewars.

Oxygen Deficiency Hazard Risk Assessment Jefferson Lab Work Area Classification

The goal of ODH risk assessment is to estimate the increase in the rate at which fatalities will occur in a given area. Controls are then designed to prevent those fatalities.

* The level of risk is based on the type of work that will be done in a given area. The level of risk is also based on expected component failure rates for the cryogenic or other equipment that presents an oxygen deficiency hazard.

At Jefferson Lab there are 5 ODH hazard levels. They are noted ODH 0 through 4. The hazard increases as the number increases. Work areas are classified assuming that there are NO CONTROLS, not even training. Dividing lines are based on the statistical probability of one worker fatality occurring in a specified number of worker-hours:

ODH Class	# of worker-hours before a fatality is expected
0	Greater than 10 million *
1	from 100,000 hours to 10 million hours
2	from 1,000 to 100,000 hours
3	from 10 to 1,000 hours
4	less than 10 hours

*10 million hours equates to over 5,000 worker years.

ODH classification is not necessary in work areas where compressed gases, liquefied gases, and volatile liquids are not stored or used.

**LOOK FOR AND OBEY REQUIREMENTS ON
SIGNS POSTED AT ODH WORK AREAS!**

NOTICE

**OXYGEN
DEFICIENCY
HAZARD** **0**

• OXYGEN DEFICIENCY HAZARD TRAINING

Halls

CAUTION

**OXYGEN
DEFICIENCY
HAZARD** **1**

PRIOR TO ENTRY ALL PERSONNEL MUST HAVE THE FOLLOWING:
• OXYGEN DEFICIENCY HAZARD TRAINING

MULTIPLE PERSONNEL IN CONTINUOUS COMMUNICATION REQUIRED

ESR

*←**

CAUTION

**OXYGEN
DEFICIENCY
HAZARD**

2

*Area
Above
Cranes Rail
in Halls.*

PRIOR TO ENTRY ALL PERSONNEL MUST HAVE THE FOLLOWING:

- PERSONAL OXYGEN MONITOR
- A SELF-RESCUE SUPPLIED ATMOSPHERE RESPIRATOR
- OXYGEN DEFICIENCY HAZARD TRAINING
- **MEDICAL APPROVAL FOR OXYGEN DEFICIENCY HAZARD WORK**

MULTIPLE PERSONNEL IN CONTINUOUS COMMUNICATION REQUIRED

DANGER

**OXYGEN
DEFICIENCY
HAZARD**

3

PRIOR TO ENTRY ALL PERSONNEL MUST HAVE THE FOLLOWING:

- PERSONAL OXYGEN MONITOR
- A SELF-RESCUE SUPPLIED ATMOSPHERE RESPIRATOR
- OXYGEN DEFICIENCY HAZARD TRAINING
- **MEDICAL APPROVAL FOR OXYGEN DEFICIENCY HAZARD WORK**

**MULTIPLE PERSONNEL IN CONTINUOUS COMMUNICATION REQUIRED
UNEXPOSED OBSERVER REQUIRED**

DANGER

OXYGEN DEFICIENCY HAZARD

4

PRIOR TO ENTRY ALL PERSONNEL MUST HAVE THE FOLLOWING:

- PERSONAL OXYGEN MONITOR
- 30-MINUTE SELF-CONTAINED BREATHING APPARATUS
- OXYGEN DEFICIENCY HAZARD TRAINING
- MEDICAL APPROVAL FOR OXYGEN DEFICIENCY HAZARD WORK

MULTIPLE PERSONNEL IN CONTINUOUS COMMUNICATION REQUIRED

CAUTION

OXYGEN DEFICIENCY HAZARD ODH-0 & ODH-1 area inside

Requirements prior to entry into ODH-0 areas :

- All personnel must have Oxygen Deficiency Hazard Training

Requirements prior to entry into ODH-1 areas :

- All personnel must have Oxygen Deficiency Hazard Training
- There must be multiple personnel in continuous communication

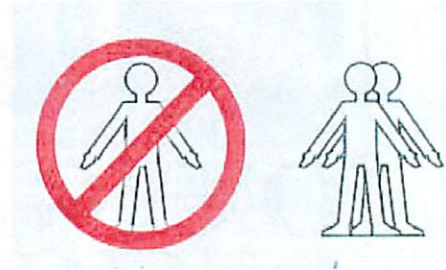
ODH Hazard Avoidance

Follow all instructions on posted ODH signs:

ODH 0/1 workers: Stay out of ODH 2, 3, 4 work areas.

NO EXCEPTIONS!

Observe the buddy rule for ODH 1 or greater.



INDICATIONS OF AN ODH INCIDENT



When you hear an alarm EVACUATE the work areas immediately. Blue flashing light and/or buzzer means ODH alarm.

Pay attention to local indications such as the sound of rushing gas, which indicates a leak.

In case of an uncontrolled release of cryogenics NEVER walk into a vapor cloud. Why? Extremely cold vapors, if inhaled, will damage lung tissue. Visibility will also be limited, increasing the chance of fall. Take an alternate exit.



ODH Assessments

An ODH assessment must be conducted whenever an ODH area is established or modified, and whenever cryogenics are used, stored or dispensed. Contact EHS staff for assistance. Do not enter the Central Helium Liquefier (CHL), the End Station Refrigerator (ESR), or the Cryogenic Test Facility (CTF) without permission from the Cryogenics Coordinator.

ODH Control Measures

Once an ODH area has been identified, specific control measures must be followed to enter that area. These controls are designed to make the risks of ODH 2, 3, and 4 areas comparable to the risk of an ODH 0 area.

These are three types of controls:

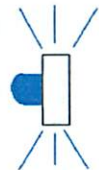
1. Engineering controls consist of:

- Fixed oxygen monitors in designated ODH 1-4 areas
- Complete filling and sealing of all penetrations leading from the Linac Service Buildings on the surface to the Accelerator tunnel below. This prevents helium from entering the Linac Service Building in the event of a helium release in the tunnel
- Helium removal systems in the Accelerator tunnel. A lintel/helium removal vent keeps helium out of the exit stairwells in the Accelerator tunnel long enough for staff to exit safely



Both fixed and portable oxygen monitors will alarm at 19.5% oxygen at Jefferson Lab.

The ODH alarm indicator is a flashing blue light (right) and/or a low-pitched buzzer.



2. **Personal protective equipment is required for work in areas classified ODH 2 or greater. Personal protective equipment includes:**

- personal oxygen monitors
- 5-minute escape packs
- self-contained breathing apparatus (SCBA) → only for ODH 4 & emergency response

All personnel entering an ODH 2 or 3 areas are required to carry a personal oxygen monitor and a five-minute escape pack.

Personal Oxygen Monitors

Personal oxygen monitors now in use throughout the laboratory are maintained by the Safety Lab. If there are problems with the monitor, notify the Safety Lab at extension 7039.



Personal Oxygen Monitor locations:

- Machine Control Center (MCC)
- Central Helium Liquefier (CHL)
- End Stations
- Safety Lab
- Cryogenic Test Facility (CTF)
- Cryomodule Test Cave (CMTF)



Mini Ox Unit - Operational Check Procedure

- Always turn the unit on in FRESH AIR. Do not turn the unit on in the ODH area because it must self check first in fresh air.
- When the monitor flashes **FAS** press the Zero button.
- The monitor will self check and set to ~ 20.8% when ready for use.

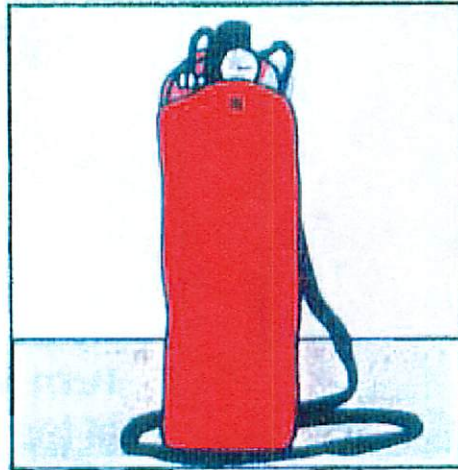
Use of the Monitor

Wear the monitor on the outside of the clothing. Do not cover the monitor with a coat or hold it in a pocket.

The personal monitors will alarm at 19.5% oxygen

Emergency Escape Packs

For ODH 2 and 3 areas, each person is required to carry their own five-minute escape pack. The MSA pack supplies five minutes of air. This section outlines the proper procedures for checking, activating, and donning the pack.



MSA

General Information

The cylinder contains a **five** minute supply of compressed air.

Do not use an escape pack if the gauge does not indicate that the pack is full. Return it to the Safety Lab for refilling. On the MSA pack the gauges are color coded. A yellow cylinder must read in the ~~yellow region on the gauge~~. A grey cylinder must read in the grey region on the gauge.

*Must read 7270psi **

Escape pack use requires annual training (SAF 210) and medical approval.

Note: The escape pack may be carried into the ODH area with a personal oxygen monitor as part of a written standard operating procedure for response to ODH alarms. However, once it is donned, the only allowable option is immediate evacuation. The escape pack is to be used for ESCAPE ONLY.

Instructions for Donning the Five Minute Escape Pack.



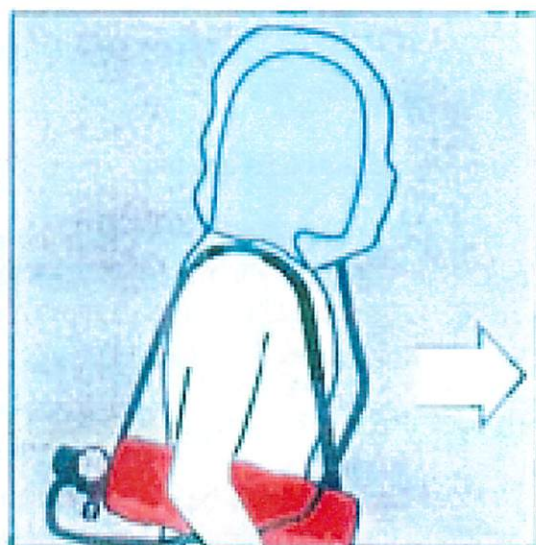
1. Check gauge



2. Turn Valve ON
at top of cylinder



3. Remove plastic hood



4. Place hood over head.
Immediately leave the
area.

Return empty or partially used packs to the Safety Lab, Bldg. 35 for refill.

Self-Contained Breathing Apparatus (SCBA)

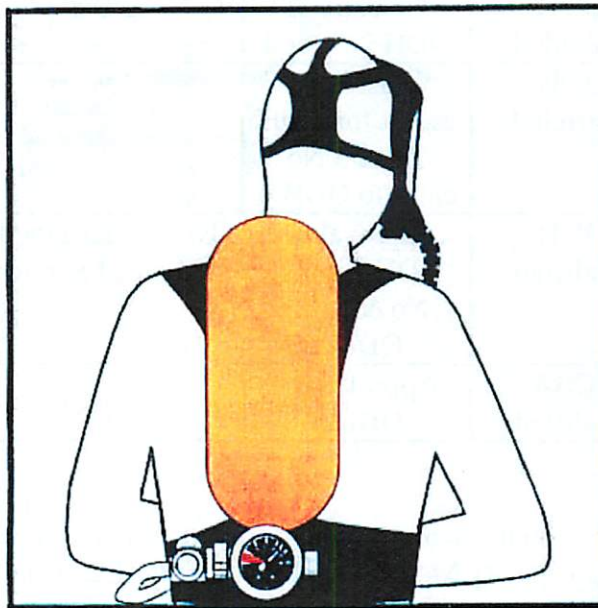
The SCBA is used only for planned work and emergency response.

Planned work - The SCBA is to be used only for entry into ODH 4 areas. Permission for entry must be received from the Cryogenic Group Leader. Most personnel at Jefferson Lab will not receive permission to enter such an area.

The SCBA provides an air supply that lasts approximately 30 minutes. SCBA use requires both an annual training class (SAF 109) in the use of the unit, an annual fit test, and medical approval.

Emergency Response - SCBA's are used for both rescue and for entry into hazardous atmospheres. When used on the Accelerator Site, the crew chief must be notified.

The SCBA provides an air supply that lasts approximately 30 minutes. SCBA use requires both an annual training class (SAF 109) in the use of the unit, an annual fit test, and medical approval.



SCBA

3. Administrative Controls:

Examples of administrative controls that may be required for ODH areas include notice, caution, and danger signs, training, use of unexposed observers, and medical approval. Important administrative controls include the Buddy Rule: Multiple personnel in continuous communication is required for entry into any area classified ODH 1 or greater.

Medical Approval Requirements

Medical approval is required only for ODH 2, 3, and 4 work. Most Jefferson Lab personnel and scientific users work in ODH 0 or 1 areas, so medical approval will not be a requirement.

ODH 0/1 workers do not need and will not have medical approval.

For ODH 2, 3, and 4 work there are four categories of medical approval

LEVEL	MEANING	DURATION OF CLASSIFICATION
ODH excluded	No entry to ODH 2, 3, or 4	3 years
ODH restricted	Must have escort for ODH 2 and 3 No entry to ODH 4	3 years
ODH qualified	Approval for ODH 2 and 3 No entry to ODH 4	To be determined by Medical Services
SCBA qualified	Approval for ODH 4	3 years


Medical approval is based on a general physical exam that includes tests of hearing, vision, blood pressure, and lung capacity. Medical approval for ODH 2, 3, and 4 is given by Jefferson Lab Medical Services.

KNOW THE REQUIRED CONTROLS FOR ENTRY INTO ODH 0 THROUGH ODH 4 AREAS

They are outlined in the following table. If at any time you are unsure of the classification of your work area, contact your supervisor and make sure you determine the classification before you enter the area and begin work.

ODH Control Measures	Hazard Class				
	0	1	2	3	4
Engineering Controls					
Ventilation - One air change per hour		X	X	X	X
Fixed oxygen monitor		X	X	X	X
North and South Linac Service Buildings, Injector Service Building: penetrations filled with stone and sealed with gas-tight gasketed aluminum plate	X				
Tunnel only: helium removal system: lintel/helium vent		X	X	X	X
Administrative Controls					
ODH Signs	X	X	X	X	X
ODH Training	X	X	X	X	X
Buddy Rule: In order to enter the work area there must be at least two workers who stay together. This is referred to as multiple personnel in continuous communication.		X	X		X
Three-man rule/Unexposed Observer 1				X	
Medical Approval			X	X	X
Personal protective Equipment					
Personal oxygen meter			X	X	X
5 minute escape pack			X	X	
Self-contained breathing apparatus					X



 NOTE: Be aware that certain work or temporary conditions may render a work area temporarily ODH 2 or above.

Any work under ODH3 or 4 conditions must be preplanned and coordinated with the Cryogenic Group Leader. A cryogenic expert will then be assigned for planning ODH3 or ODH4 work.

The Three-Man Rule/Unexposed Observer: An unexposed observer is required for ODH 3 work. An unexposed observer is an ODH-qualified worker who is physically removed from an ODH 3 area and can monitor work activities. In case of an ODH incident the unexposed observer can summon help.

EMERGENCY PROCEDURES

PROBLEM	RESPONSE
Installed oxygen monitor alarms	<ul style="list-style-type: none"> • EVACUATE • notify crew chief* • do not enter work area until problem has been solved
Any indication of possible gas leak, such as: vapor cloud or sound of rushing gas	<ul style="list-style-type: none"> • EVACUATE the work area • notify crew chief*
Any indication of an ODH situation and a worker is DOWN	<ul style="list-style-type: none"> • EVACUATE • call 911 • notify crew chief*
Personal oxygen monitor alarms	<ul style="list-style-type: none"> • don escape pack and EVACUATE the area (ODH 2) • Troubleshoot monitor • notify crew chief of potential ODH problem if monitor has not malfunctioned*
Not enough oxygen monitors for all members of work group to enter an ODH 2 or greater area	<ul style="list-style-type: none"> • DO NOT ENTER area until each member has a personal oxygen monitor
Work group enters an ODH 2 area with personal monitors. One monitor is dropped and malfunctions.	<ul style="list-style-type: none"> • due to the buddy rule, two workers will have to exit together
Workers experiences health effects associated with ODH.	<ul style="list-style-type: none"> • EVACUATE the work area • call 911 • notify crew chief

*If incident occurs on the accelerator site, notify crew chief and supervisor.
If incident occurs elsewhere, notify supervisor.

Permanent ODH Areas at Jefferson Lab

As of 12/06: For current classification consult EHS staff.

ODH Classification	Location
ODH 0	North and South Access Building Electronic Rack rooms North and South Linac Service Buildings Injector Service Building Experimental Halls Test Lab multiple areas.
ODH 0 and 1	Tunnel Lower Level behind cryomodules is ODH 1; ceiling is ODH 1; rest of tunnel is ODH 0 FEL Vault: ODH 0 and 1 FEL Upper Level: Inside designated electronic racks is ODH 1, rest of building is ODH 0. Test Lab Cryomodule Test Cave: -ODH 0 when u-tube not connected to cryomodule, large cave door open. -ODH 1 when u-tube connected, large cave door open. Central Helium Liquefier Building (Bldg. 8): ODH 0 when walking through, ODH 1 when working inside.
ODH 1	End Station Refrigerator Building ESR (bldg. 102) Cryogenic Test Facility (bldg. 57)
ODH 2	Experimental Halls: Area above the crane rail Test Lab Cryomodule Test Cave Mezzanine Test Lab Cryomodule Test Cave: cryomodule u-tube connected, large cave door closed.
ODH 3	no permanent area
ODH 4	no permanent area

Estimating Oxygen Concentration

The equation for estimating oxygen concentration in the work area if the contents of a compressed gas 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

Resulting oxygen concentration percentage must be at least 19.5%.

*For compressed gas bottles V_g can range from 200-300 cubic feet, depending on the gas and the type of cylinder. Check with the gas supplier. Use room volume in cubic feet.

**For a cryogenic container, V_g is number of liquid liters x expansion ratio (700-1000)/1000 liters per cubic meter. Convert the room volume to cubic meters.

Last Revision: December 2006