


National High Magnetic Field Laboratory Safety Program

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Overall Mission and Overview:

The National High Magnetic Field Laboratory (NHMFL) Environmental, Health, and Safety (EHS) program's mission is to:

Provide support and guidance to all NHMFL departments with the implementation, maintenance and review of a comprehensive environmental, health, and safety program. The goal of the MagLabs EHS program is to control, reduce or eliminate work-related injuries, illnesses and loss of NHMFL resources.

The NHMFL is charged by the National Science Foundation (NSF) to safely:

- Promote magnet-related research to serve an interdisciplinary scientific user community.
- Provide unique high-magnetic-field facilities through a competitive and transparent proposal review process.
- Advance magnet and magnet-related technology.
- Partner with universities, other national laboratories and industry to enhance national competitiveness in magnet and related technologies.
- Serve the NSF as a prominent example of its successful stewardship of large research facilities.
- Support science and technology education in the United States.
- Increase diversity in the science, technology, engineering, and mathematics workforce.
- Promote collaboration among our three partner institutions: Florida State University (FSU), the University of Florida (UF) and Los Alamos National Laboratory (LANL).



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1.0 PURPOSE

This Program establishes policies and procedures to be observed by all personnel at the NHMFL when working with cryogenics or rooms containing cryogen materials during experimentation and research.

The policy of the NHMFL is to provide and maintain a safe and healthful working environment. Employees and users alike must assist in ensuring that safety is not compromised. The safety and health of employees and users is the inherent responsibility of each employee, user, management, and all levels of supervision.

2.0 SCOPE

This document assigns responsibilities, provides safety guidance, and defines actions to be taken to protect workers from the hazards involved with the use of cryogenics and oxygen deficiency hazards.

3.0 REFERENCES

- 3.1 Liquid Cryogenics by K.D. Williamson and F.J. Edeskuty
- 3.2 ASME section VIII
- 3.3 CGA S-1.1, CGA S-1.2, CGA S-1.3
- 3.4 API510, API520
- 3.5 DOT 49 CFR 173

4.0 DEFINITIONS AND ACRONYMS

Cryogen: Any fluid that liquefies below 123 K (~ -238 °F) at atmospheric pressure. This includes helium, hydrogen, neon, nitrogen, oxygen, argon, krypton, xenon, methane, ethane, and propane. Solid carbon dioxide, or dry ice, should also be considered a cryogen as the safety concerns are similar. Other lesser-used cryogenics include carbon monoxide, nitrogen trifluoride, hydrogen sulfide and some other hydrocarbons.

5.0 ROLES AND RESPONSIBILITIES

The **Principal Investigator (PI)** is responsible for the safe use of cryogenics in the PI's laboratory. The PI must notify the Safety Department of any changes in cryogen use, such as a change in quantity or space that may change the Oxygen Deficiency Hazard (ODH) classification. The PI is responsible for:

- Maintaining all cryogenic equipment in accordance with manufacturer's recommendations. Any equipment, which does not meet manufacturer's operating specifications, must be removed from service.



- Ensuring that all personnel that work in their area have completed the online Cryogen Safety Training and have demonstrated proficiency in working safely with cryogens through on the job training.
- Developing, maintaining, and updating, as needed, all operating procedures (SOP's) for the facility under the PI's control.
- Acting as the contact for the Safety Department.
- Enforcing the NHMFL Cryogen Safety Program and the requirements of their lab specific Oxygen Deficiency Review.
- Supervising all spectators, visitors and personnel with access to their area to ensure against unauthorized entrance or accidental exposure.
- Reporting all incidents involving safety violations or injury to the Safety Department at 855-SAFEMAG (723-3624).
- Ensuring that all personal protective equipment in the area is properly maintained.

Laboratory Personnel are responsible for adhering to the safe use of cryogens in the lab. They must observe all safety precautions and operating procedures while using cryogens and must inform the PI and NHMFL Safety Department of any apparent safety problems associated with the use of cryogens. Each lab member must be adequately trained as defined in this Program. Laboratory Personnel are responsible for:

- Following laboratory administrative controls and SOP's while working with cryogens.
- Keeping the PI fully informed of any departure from established safety procedures. This includes notification of an exposure incident.
- Taking the NHMFL online Cryogen Training Course and completing cryogen on the job training.

The **Safety Department** is responsible for the following:

- Conduct and recordkeeping of ODH reviews for cryogen containing labs.
- Inspect fixed oxygen deficiency monitors and keep a record of inspection report.
- Provide assistance in evaluating and controlling ODH and cryogen hazards.
- Update the Cryogen Safety Program when necessary.
- Maintain online training records.
- Participate in accident investigations involving cryogens.

6.0 CRYOGEN HAZARDS

6.1 Extreme Cold Hazard



Cryogenic liquids and gas vapors can produce effects on the skin similar to a thermal burn. Brief exposure can damage delicate tissues such as the eyes. Prolonged exposure or contact with cold surfaces can cause frostbite. Cold burns have similar symptoms to hot burns and may blister.

6.2 Asphyxiation Hazard

Several working fluids (gases and liquids), including cryogenics, have the potential to displace the oxygen in a room. When this happens asphyxiation and death can occur. Oxygen deficiency is a serious hazard in enclosed or confined spaces when the space size is comparable to the potential oxygen-displacing gas volume. For Confined Spaces requirements see SP-30. The effects of an oxygen deficient environment are insidious, sudden, and occur without warning. Just two breaths without oxygen can cause loss of consciousness.

Normal atmospheric gas composition at sea level contains 20.9 % oxygen. An ODH environment is defined as having less than 19.5 % oxygen. Health effects of low oxygen content are listed below for varying oxygen content.

See section 13.0 CONTROLLING FOR OXYGEN DEFICIENCY HAZARDS (ODH) for more information on controls.

CAUTION: Oxygen levels of less than 12% can cause unconsciousness suddenly and without warning. Do not assume that if you are in an oxygen deficient atmosphere that you will be alright if you take a deep breath and hold it.

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

6.3 Storage Tank Failures

If a storage tank fails then the containing liquid and gases may be released into the surrounding area. Storage tanks can fail due to impact from projectiles, cold exposure on the outside of the tank, vacuum jacket leak, and aged burst discs or relief valves.

If the seal on the vacuum jacket is broken then large amounts of heat is introduced into the cryogen, which will cause it to vaporize and expand. Each cryogen has a unique expansion ratio: helium (757:1), nitrogen (696:1), argon (847:1), hydrogen (851:1), and oxygen (860:1). Each of these cryogens has the potential to increase the pressure in an enclosed container to over 100 MPa (14,000 psig). Cryogen containment systems are covered in section **9.0 CRYOGEN CONTAINMENT SYSTEMS AND DEWAR SAFETY**.

6.4 Toxic Hazards

Each gas has specific negative health effects. For example, liquid carbon monoxide can release large quantities of carbon monoxide gas, which can cause death almost immediately. Refer to the material safety data sheet for information about the toxic hazards of a particular cryogen.

6.5 Flammability Hazards

Any flammable gas also has flammability hazards associated with its liquid state. Fires can occur when any fuel and oxidizer are exposed to an ignition source such as static electricity, electrical shorts, or lighting. Liquid oxygen (although not in itself flammable) can create an oxygen rich environment, which can increase the flammability hazard. Liquid oxygen (boiling point of 90 K) can liquefy on pipe insulation and pipes containing liquid nitrogen (boiling point of 77 K).

7.0 LIQUID OXYGEN AND LIQUID OXYGEN SYSTEMS

The NHMFL does not liquefy or distribute liquid oxygen. Liquid oxygen is pale blue and magnetic. Although oxygen is nonflammable, it is a strong oxidizer and can increase the



flammability hazards. Liquid oxygen is inadvertently made during liquid nitrogen transfer using uninsulated lines and can create an oxygen rich environment, which is more susceptible to ignition. Ensure that the liquid oxygen does not pool and avoid ignition sources in the vicinity of cryogen transfers.

Although liquid oxygen does not pose as much as an asphyxiation hazard as liquid helium and nitrogen, high oxygen content above 80% is known to cause irritation of the respiratory tract, decrease in vital capacity, coughing, sore throat, and chest pain.

If you plan to use liquid oxygen at the lab, you must notify the Safety Department before usage.

8.0 FLAMMABLE CRYOGENS

Flammable cryogens include: hydrogen, methane, and liquefied natural gas. Besides the risk of cryogenic burns or asphyxiation, flammable cryogens pose a significant risk of fire or explosion because a large amount of flammable material is condensed into a relatively small volume. Intentional or accidental release of the vapor can quickly form combustible gas mixtures, which can easily diffuse into areas where an ignition source is present.

If you plan to use flammable cryogens at the lab, you must notify the Safety Department before usage.

9.0 CRYOGEN CONTAINMENT SYSTEMS AND DEWAR SAFETY

Dewars are containers that utilize a vacuum jacket to stop conduction and convection heat transfer. Pressure relief devices, such as relief valves and rupture discs, should be present on all cryogen containment systems or trapped volumes to vent over-pressurization to avoid explosions and shrapnel.

Inspect and maintain cryogenic systems and equipment on a regular basis. Ensure all safety valves and vent valves are unobstructed and functioning properly. Check the pressure relief devices on liquid nitrogen tanks weekly.

Ordinary glassware must not be used to store or transfer cryogenic liquids. All unprotected glass dewars must be wrapped with a heavy adhesive tape to prevent fragmentation and to provide a better gripping surface. The materials used in cryogenic systems must have the appropriate physical properties to qualify them for use at these extremely low temperatures.

All liquid nitrogen and liquid helium dewars must be made from non-magnetic materials. Any magnetic dewar will be taken out of service.



For additional information about pressure relief devices reference ASTM Section VIII Boiler and Pressure Vessel Code, CGA S-1.1 Pressure Relief Device Standards Part 1- Cylinders for Compressed Gases, CGA S-1.2 Pressure Relief Device Standards Part 2- Portable Containers for Compressed Gases, CGA S-1.3 Pressure Relief Device Standards Part 3-Stationary Storage Containers For Compressed Gases, API510 Pressure Vessel Inspection Code.

Below are several topics related to dewars you should know about regarding their safe operation:

9.1 **Burst Disc**

A burst disc (or rupture disc) is a non-reclosing pressure relief device. Once the disc is ruptured, it must be replaced before the system is put back into operation. If a dewar burst disc ruptures do not attempt to fix it. Notify the Safety Department or a Cryogenics Operator to assess the situation. Never cap or block a ruptured burst disc. Helium dewars and liquid nitrogen dewars burst disc ratings are determined by the manufacturer. Check with the manufacturer for the correct rating.

Pressure relief code CGA S-1.3 (and other CGA documents like M-1-2013 Section 13.1.1) states: Burst discs and relief valves operating outside need to be replaced every five years. API510 6.6.3.2 states that pressure relief devices should be tested or replaced every 10 years for clean (non-fouling) and noncorrosive services.

Never change the pressure reliefs or burst disc. You must consult a Cryogenics Operator about any broken dewars.

9.2 **Relief Valve**

A relief valve is a reclosing pressure relief device and has a lower pressure rating than the burst disc. Liquid helium and nitrogen dewars relief valves ratings are determined by the manufacturer. Check with the manufacturer for the correct rating.

Only a rupture disk device may be used as the sole pressure-relieving device on a vessel.

Never change the pressure reliefs or burst disc. You must consult a Cryogenics Operator about any broken dewars.

9.3 **Vacuum Jacket Failure**

Vacuum jacket failure is loss of insulating vacuum and will cause the cryogen to rapidly boil off. These failures can be caused externally by joint failures or sudden impact as well as internally from piping failure.



Inspect the dewar during a fill. If there is condensation on the outside of the dewar you may have a leak into the vacuum jacket.

You must consult a Cryogenics Operator about any potentially broken dewars.

9.4 Dewar Handling Practices

- Follow all transportation requirements listed in 14.0 TRANSPORTATION REQUIREMENTS (ON/OFF SITE)
- Cover any open dewar when not in use with a loose fitting cover that allows boil-off to vent.
- Do not remove dewars from the building. If you need a dewar transported between buildings call Airgas.
- Keep dewars upright. If a dewar is accidentally tipped, back away, secure the area, alert others in the area, contact Safety immediately using SAFEMAG (Dial 855-SAFEMAG). Safety will assess any damage and wait until the pressure is low enough to stop venting then use at least two people to set upright while wearing proper personal protective equipment (PPE). Do not attempt to move a tipped dewar without the Safety or Cryogen Department.
- Take your time moving dewars. Look for the easiest path and avoid narrow paths on an incline (ie. the outside walkway between MS&T and the loading dock).
- When using a crane never lift by the handles or by wrapping slings around the shell. Only use dedicated lifting eyehooks or an approved carriage. Crane training is required to use the crane.
- Position dewar so that the relief valve and burst disc are directed away from personnel.
- Check that the dewar is properly labeled with the name of the cryogen. Do not cross contaminate dewars.
- Never use a broken dewar.

9.5 Thermal Stress Issues

Use containers made especially for ultra-low temperatures to store cryogenes. Material properties change with temperature. Certain materials are not suitable for cryogen containment. For example, carbon steel is stronger than stainless steel at room temperature but becomes extremely brittle at low temperature and is very susceptible to fracture.

At low temperatures solids contract. Joining two or more different materials at cold temperatures may induce very large mechanical stress as each material has its own contraction rate. When added to cold embrittlement, cold metal joints can easily fail without proper engineering. Learn the properties of any material you subject to cold temperatures.



9.6 Leak Response

Small cryogenic leak response (liquid nitrogen, 100, 250 or 500L helium dewars) should be handled by experienced personnel only, using proper PPE. The equipment is designed to vent cryogens safely until pressure has been reduced sufficiently or until the cryogens are gone. No action is MANDATORY as long as people remain a safe distance away.

A large cryogenic leak (liquid nitrogen tank) may require emergency response but should always be handled by a Cryogenics Operator or the Safety Department. SP-5 LN₂ Rupture Disk provides more details about liquid nitrogen storage tank rupture disc actuation.

10.0 CRYOGEN TRANSFERS AND HANDLING

Cryogen exposure is most likely to occur during a cryogen transfer. Principal investigators must develop and implement standard operating procedures involving cryogens for their lab space. All personnel working with cryogenic fluids must be appropriately trained on their specific lab's operating procedures.

All uncontrolled releases of cryogenic liquids or gasses must be reported to the Safety Department immediately.

Rules that should be included in all lab's operating procedures:

- Do not directly touch or make contact with cryogenic liquids or uninsulated cryogenic equipment or pipes. Tongs can be used to withdraw objects immersed in a cryogenic liquid. Long exposer to cold temperatures can penetrate through gloves and still cause burns.
- Do not overfill containers.
- Pour or transfer slowly to minimize boiling and splashing.
- Avoid the path of boil-off gases. Venting fluids (liquids or cold gases) should not contact any part of the body.
- Ensure that cryogenic fluids are stored in insulated containers designed to handle cold temperatures.
- Containers of cryogenic liquid must never be closed to prevent proper ventilation. Where a special vented stopper or venting tube is used, as on some small portable containers, the vent must be checked regularly to ensure it has not plugged with ice formed from water vapor condensed from the air.
- Ensure that appropriate personal protective equipment is worn when working with cryogens.
- Ensure that an oxygen alarm is present in the work area when appropriate. Check that the oxygen alarm has been checked within the past 6 months, if not notify the Safety Department.
- Always handle in well-ventilated area.



- Do not store cryogenics in a confined space.

Cryogen handling PPE should include a face shield and 100% skin coverage with cryogen safe fabrics, sturdy closed-toed shoes, and no cuffs on pants. Avoid materials that may soak up large amounts of liquid. See section 16.0 PERSONAL PROTECTIVE EQUIPMENT for more information.

Liquid Nitrogen

The lab has three large liquid nitrogen tanks (10,000, 6,000 and 3,000 gallons). They are filled via tanker truck several times a week. Please avoid the tanks during a fill. If you notice a leak in or around a liquid nitrogen storage tank contact the Safety Department.

Liquid Helium

Liquid helium transfers in the lab should follow your specific lab's operating procedures. Perform at least five transfers with your lab supervisor before attempting on your own. Your specific lab may require two people to transfer liquid helium depending on the setup.

11.0 OPERATIONS: LIQUID HELIUM USE AND RECOVERY

The Maglab has a Linde LR280 helium liquefier capable of liquefying ~200 L/hr. This system includes a compressor, purifier, expansion turbines, helium gas storage, and a recovery system. Only Cryogenics Operators may operate and perform maintenance on this system. Do not enter the helium compressor room without first contacting a Cryogenics Operator. The helium compressor room is designated as ODH class 1.

Helium recovery lines are connected through the building. Vent all liquid helium dewars to the recovery line when not transferring. If a pipe labeled helium recovery is leaking, contact the Safety Department.

Liquid helium dewars are filled by a Cryogenics Operator. They are available for pick-up along the wall across from cell 14. To order liquid helium go to the main website under user support.

12.0 OPERATIONS: LIQUID NITROGEN USE

Nitrogen fill station and dewar filling

Liquid nitrogen fill stations are available in OPMD across from cell 15, the C-wing loading dock, and the NMR wing loading dock. Follow instructions given at the specific fill station. A badge reader limits use of the fill stations until your lab supervisor has trained you. After training have your supervisor email the Safety Department to add your name to the fill stations.

13.0 CONTROLLING FOR OXYGEN DEFICIENCY HAZARDS (ODH)



Before oxygen-displacing gases, including cryogenics, can be introduced into a working area an ODH Safety Review Form (APPENDIX 1: ODH SAFETY REVIEW FORM) must be completed. This form will document the lab location, lab manager, list of gas sources and ODH calculation. The form will then instruct whether an ODH Risk Assessment needs to be performed to determine the ODH classification. The form includes sections for documenting the engineering and administrative controls.

ODH Risk Assessment

If an ODH Risk Assessment is required by the ODH Safety Review then the following method, developed at Fermi Lab (FESHM Ch. 4240) and used at Jefferson Lab (ES&H Manual Ch. 6540 Appendix T1) and SLAC (ESH Manual Ch. 36), will be used. This assessment begins with an estimation of the ODH fatality rate.

Estimation of ODH Fatality Rate

The goal of an ODH risk assessment (an example is provided in APPENDIX 4: EXAMPLE ODH RISK ASSESSMENT CALCULATION) is to estimate the rate increase in the occurrence of fatalities because 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 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 ϕ = the ODH fatality rate (per hour)
 P_i = the expected rate of the i^{th} event (per hour), and
 F_i = the probability of a fatality due to event i^{th} .

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

Estimation of Event Rate P_i



The event rate P_i is the expected rate per hour of the i^{th} type event where i is any possible ODH event in the space. Ideally, the event rate should be determined from operating experience at the NHMFL. Event rates are given in FESHM Ch. 4240. An Event Rate for magnet quenches will be determined for each magnet undergoing an ODH assessment.



Event Rate P_i		
1. Dewar failure		$P = 1 \times 10^{-6} / \text{hr}$
2. Electrical failure		$P = 1 \times 10^{-4} / \text{hr}$
3. Fitting failure		$P = 5 \times 10^{-7} / \text{hr}$
4. Magnet failure		$P = 2 \times 10^{-7} / \text{hr}$
5. Piping failure		$P = 1 \times 10^{-8} / \text{hr}$
6. Pump failure		$P = 1 \times 10^{-6} / \text{hr}$
7. Magnet quench (tbd for each magnet)		$P = \text{-----} / \text{hr}$

Estimation of Fatality Factor F_i

The fatality factor 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 fatality factor F_i and the lowest attainable oxygen concentration is provided by FESHM Ch. 4240.

Oxygen Concentration	Fatality Rate
$O_2 < 8.8\%$	$F = 1$
$8.8\% < O_2 < 18\%$	$F = 10^{0.76(8.8\%O_2)}$
$O_2 > 18\%$	$F = 0$

Fatality Rate relationship with oxygen concentration

ODH Classifications and their Required Controls

Higher ODH Classes (3 and 4) will be avoided for normal operational use. If a space is not ODH labeled and an ODH environment is suspected, only proceed if you have a personal O_2 monitor (see APPENDIX 2: PERSONAL OXYGEN MONITORS). Confined spaces (see SP-30) are not classified, as they are not intended for normal occupancy.



ODH Classification	Required Controls
<p style="text-align: center;">ODH 0</p> <p>Estimated fatality rate > 10 million hours</p>	<p>ODH certification</p> <p>May have administrative or passive engineering controls present (if so, sign required)</p>
<p style="text-align: center;">ODH 1</p> <div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 10px auto;"> </div> <p>Estimated fatality rate: 100,000 to 10 million hours</p>	<p>ODH certification</p> <p>Caution sign</p> <p>ODH training for all lab workers</p> <p>ODH awareness briefing for visitors</p> <p>Installed oxygen monitor¹</p> <p>Administrative access control</p>
<p style="text-align: center;">ODH 2</p> <div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 10px auto;"> </div> <p>Estimated fatality rate: 1,000 to 100,000 hours</p>	<p>ODH certification</p> <p>Caution sign</p> <p>Personal oxygen monitor for each individual</p> <p>ODH training for all lab workers</p> <p>Two-person rule</p> <p>Installed oxygen monitor</p> <p>Administrative access control</p>

¹ Area monitor may be waived for temporary systems or operations at the discretion of a safety review panel and approval from the Cryogenic Safety Committee leader.

The Safety Department will perform a biannual ODH equipment inspection. This will include testing the ventilation systems, area monitors, and alarm systems (lights and horns). An ODH equipment inspection tag will be attached to all ODH systems with an inspection date within the prior six months. Please contact the Safety Department if you find an ODH system that has not been checked within this timeline.



In the Event of a Potential Oxygen Deficiency Hazard

13.1 Response to an alarm from a personal oxygen monitor:

If anyone is working in an area and his/her personal oxygen monitor alarms, the person(s) and anyone in the area must immediately evacuate, and call 855-SAFEMAG to report an emergency.

13.2 Response to an alarm from a fixed oxygen monitor:

If anyone is working in an area and a fixed oxygen monitor alarms, the person(s) should evacuate the area going away from the source of the alarm. After exiting, they should notify the person (i.e. Principal Investigator, Supervisor, Operations etc.) responsible for the area as well as calling 855-SAFEMAG to report an emergency. They should not re-enter until the problem has been resolved.

13.3 Response to other indications of a possible cryogen or gas leak (vapor cloud, sound of gas leak, etc.):

If anyone is working in an area and notes an indication of cryogen leak, they should notify the person (i.e. Principal Investigator, Supervisor, Operations etc.) responsible for the area. If a fixed or personal oxygen monitor begins to alarm, follow the above sections, evacuate the area, and contact personnel.

13.4 Entry into an area with unusual oxygen deficiency hazards:

Any rescue must be conducted by emergency (Fire Department) personnel. If an area is suspected to be oxygen deficient or to present an elevated risk for oxygen deficiency hazards, an unexposed observer and the use of self-contained breathing apparatus (SCBA) equipment are required. Florida State University and the Mag Lab do not support the use of SCBA equipment by employees for rescue purposes.

The following steps should be followed when investigating an area suspected to present an elevated risk for oxygen deficiency hazards and rescue is not required:

- Evacuate the area.
- Inform the Safety Department at 855-SAFEMAG.
- Inform the supervisor of the affected area.
- The Safety Department will establish barriers to prohibit personnel from entering the area.
- The supervisor will work with the Safety Department and Operations groups to remotely determine the status of the area alarm, if active.
- If the cause of the alarm appears to be loss of power (0% oxygen level and no apparent signs of an ODH), wait for power to be restored to the unit. When power is restored and normal readings return (or if maintenance is required), follow two-person rule and carry personal monitors when first reentering the area.



- If the alarm appears to be due to an actual ODH, or if there are no fixed alarms in the area, try to remotely discern and resolve the cause for the ODH. If this cannot be safely done, the Safety Department will work with the Fire Department and the area supervisor to determine how to safely enter the area to resolve the cause of the ODH.

14.0 TRANSPORTATION REQUIREMENTS (ON/OFF SITE)

14.1 Onsite transportation

- Do not transport filled open dewars. Cover them loosely when not in use to prevent accumulation of moisture and formation of ice. Use the cap supplied with the dewar.
- Never seal containers of cryogenic fluids. Inadequate venting can result in excessive gas pressure, which can damage or burst a container.
- Never ride in elevators with dewars of any size or compressed gas cylinders. The small space may become oxygen deficient.
- Lifting and carrying full dewars with more than 25 liter is a two-person task and should not be carried out alone.
- Do not attempt to control a dewar from its downhill side on a ramp. Do not pull the dewar behind you when traveling down a decline. You can easily lose control of the dewar in this position which may result in injury.
- Position dewars so that pressure relief valves and rupture disk vent paths are directed away from personnel, critical equipment or work areas.
- Cryogenic equipment must be kept clean and located away from open flames or sparks as condensing air may pool producing an oxygen rich environment.

14.2 Offsite Transportation

Cryogenics delivered offsite increase the opportunities for spilling these liquids and exposing the public to harm so keep safety in mind. All onsite transportation requirements apply including: cryogenic safety training, use of approved vessels, PPE availability, and ODH considerations. Transporting cryogenics off the laboratory property is limited to liquid nitrogen. For offsite cryogenics, consider delivery by AirGas or other suitable transportation company. Dewars must be returned with a liquid level > 1%.

- The destination laboratory or facility may have local rules for the use of cryogenics and should be respected.
- Never dispose of liquid nitrogen in a confined area or pour it down the sink.
- When rolling dewars outside, stay clear of grates, large cracks, uneven portions of the pavement and any other hazards, which could catch a wheel and cause tipping.
- Cryogen filled dewars must not be transported within closed vehicles. Cryogenics can only be transported in open vehicles such as flatbed trucks, pickup trucks, or via a support designed to keep the cryogen external to the vehicle's passenger space.



- Cryogen dewars must be properly secured to the vehicle during transportation.
- Laboratory personnel must maintain control of the dewar while transporting and at the offsite location.

15.0 OPERATIONAL SHUTDOWN PROCEDURE

Every lab or group should have their own Emergency Action Plan. This may include how to handle a cryogenic system during a power outage, fire, hurricane, and a fire alarm. Make sure your lab has discussed the safest procedure for lab members and equipment during an operational shutdown.

16.0 PERSONAL PROTECTIVE EQUIPMENT

All personnel handling cryogenics and with the possibility of exposure to cryogenic liquid or vapors should have at a minimum hand protection, eye protection, closed toed shoes, long sleeves and pants without cuffs. Face shields are required when operating a system under pressure, when connecting or disconnecting lines or components, and when venting except where the vent system releases away from the personnel. Unprotected body parts should not touch uninsulated pipes or vessels, which contain cryogenics. The cold temperature will cause the flesh to stick and tear when one attempts to withdraw.

Leather or cryogen specific gloves should be worn when handling anything that is exposed to cold liquids or vapors. Gloves should fit loose and be capable of being removed quickly. Adequate footwear should be worn with no open or porous shoes. Pants should be un-cuffed and left outside of the shoes to avoid pooling.

Any clothing that has been splashed or soaked with oxidants should be removed until completely free of the gases. Personnel exposed to oxidants should avoid ignition sources until completely free of the gases.

17.0 SAFETY TRAINING

To be authorized by the NHMFL to handle or transfer cryogenic fluids, individuals must complete Lab Safety and Cryogen Safety Training as well as being trained in your specific lab's cryogen work procedure.



APPENDIX 1: ODH SAFETY REVIEW FORM

This form is used to document the safety review required before introducing oxygen-displacing gases, including cryogenics, into the work area. This form also covers changing/ modifying systems or operations involving oxygen-displacing gases. This form is to be completed by the Safety Department and approved by Cryogen Safety Committee leader. A copy of this form will be held by the Safety Department and by the lab manager of the reviewed lab.

1 General Information

Preparer		List of gas sources:	Type (He/N2)	Amount (L)
Lab manager				
Location (bldg/rm/area)				
Description of system				
Gas source:	helium nitrogen argon other			

2 Preliminary ODH Calculation

Identify the largest gas source above and perform the following:

Total volume of the room ^a , $V_R(\text{ft}^3) =$	
Volume of gas at room temperature and pressure ^b , $V_G(\text{ft}^3) =$	
Calculate oxygen level, $21(V_R - V_G)/V_R =$	
Will ventilation be maintained during building power failure ^c ?	yes No

^a Total room volume is calculated as length x width x height.

^b Convert liquid volume (liters) to gases volume (ft³): for helium multiply by liquid volume in liters by 26.8 (ft³/L), for nitrogen multiply by 24.6 (ft³/L).

^c If there is no active ventilation during a power failure, further evaluation is required to show that the area has sufficient passive ventilation or mitigations are in place to assign a ODH 0 classification.

If the resulting oxygen level is $\geq 19.5\%$ normal or $\geq 18\%$ during system upset	Sign form and submit for approval
If the resulting oxygen level is $< 19.5\%$ normal or $< 18\%$ during system upset	Conduct an ODH risk assessment (see SP-4 Cryogenics Section 10) and attach.



3 Approvals

Person	Name	Signature	Date
Preparer			
Lab Manager			
Cryogen Safety leader			
ODH Classification			
Comments			

4 Additional Information for Risk Assessment

To be completed by the review document preparer from the Safety Department	
<p>Engineering Controls</p> <p>Example:</p> <p>Mechanical ventilation</p> <p>Fume Hood</p> <p>Valves</p> <p>Critical orifices</p>	
<p>Administrative Controls</p> <p>Example:</p> <p>Training Required</p> <p>Standard protective measures</p> <p>Work control documents</p>	
<p>Attachments</p> <p>List all that apply:</p>	



Communications	
Risk assessment	
Complex volume calc.	

5 Additional Comments

General Information	
Approval	
Risk Assessment	



APPENDIX 2: PERSONAL OXYGEN MONITORS

The lab uses two types of oxygen monitor. The first type is the MSA ALTAIR, which is currently being phased out. The second type, the RKI OX-03, is being introduced as the new oxygen sensor in the lab due to its ability to be calibrated and simple to perform bump test.

MSA Altair Pro Personal Oxygen Monitor

To turn on unit:

- **TURN ON IN FRESH AIR.**
- Press the power button and hold until lights flash twice.
- Unit will go through test mode of alarms
Display will read "FAS?" (fresh air sample)
- Press power button to initiate this fresh air
- FAS test should be performed monthly
- Unit will display ok if FAS is good**

** If unit does not pass FAS, a calibration is required. Call 855-SAFEMAG to have the unit calibrated.



To Perform Bump Test:

- Hold power button down for 2 seconds.
- Unit will display Test
- Release power button
- The unit will display "GAS?"
- Press power button again
- Hourglass will appear above the word GAS
- Hold the unit up to your mouth and breathe on the white sensor until the display reads OK and you hear an audible beep
- A check mark √ will appear above the O2 reading: this indicates that the bump test is current and WILL HOLD FOR 24 HOURS
- To turn off unit: hold down power button until long tone is heard.
- YOU MUST PERFORM THE DAILY BUMP TEST



RKI OX-03 personal oxygen monitor

To turn on unit:

- Turn on in fresh air.

To perform bump test:

- **Hold down AIR button, wait for two beeps, release.**
- You must perform a daily bump test.
- Fast changes in temperature or pressure can affect the reading.

** If unit fails the bump test call 855-SAFEMAG to have the unit calibrated.

Use of the Monitor:

- Wear the monitor on the outside of the clothing on shoulder/collar area.
- Do not cover the monitor under a coat or hold it in a pocket.
- The personal monitors will alarm at 19.5% oxygen.





APPENDIX 3: FIXED OXYGEN MONITORS

The lab uses fixed oxygen monitors in areas containing large volumes of cryogens or rooms classified as ODH Class 1 or 2. The oxygen monitors are Pureaire TX-1100-DRA. These monitors come with a built in horn and alarm at oxygen levels below 19.5% and above 23.5%.



These meters will be accompanied by a blue light that will begin to strobe if the meter alarms a low oxygen environment. In larger rooms the meter will also have a second, louder, horn for alarming to ensure that all nearby personnel are aware of an oxygen deficiency. There will be signs explaining that the alarm and blue light indicate a low oxygen environment and that the room should be evacuated in the event of an alarm.

The fixed oxygen meters will also be connected to an uninterrupted power supply that will allow them to continue monitoring in the event of a power failure.

The oxygen monitors in the DC magnet building are connected to the plant distributed control system where their information will be monitored and logged. Should these monitors stop functioning, the DCS will initiate an alarm in the monitors' rooms to alert workers.

These monitors will be inspected and tested every six months by either the Safety Department or Cryogenics Group.



APPENDIX 4: EXAMPLE ODH RISK ASSESSMENT CALCULATION

Simple Example:

Assume a 24' x 18' x 10' laboratory space housing 100 L dewar of liquid nitrogen and 50 L dewar of liquid helium.

Step 1:

- A. Determine the volume of the room in liters. Total room volume is calculated as length x width x height. $V_R = 122,330$ L
- B. Determine the volume of the gas source at 1 atm and at room temp. Covert liquid volume (liters) to gases volume (liters) using the expansion ratio: for helium multiply by liquid volume in liters by 757, for nitrogen multiply by 696. $V_{GHe} = 37,850$ L, $V_{GN_2} = 69,600$ L
- C. For each gas source determine the resulting O₂ if normal air is displaced by the gas.
 $O_2\% = 21(V_R - V_G)/V_R$, $O_2\%_{He} = 14.5\%$, $O_2\%_{N_2} = 9.05\%$,

Step 2:

Determine the estimation of Event Rate P_i given in section 10 for a given failure: for dewar failure, $P = 1 \times 10^{-6}$ /hr.

Step 3:

Determine the Fatality Factor F_i given in section 10 for each resulting O₂% level: for the He source $F_{i_He} = 4.64 \times 10^{-5}$, $F_{i_N_2} = 0.644$

Step 4:

Multiply each Event Rate with the corresponding Fatality Factor and take the summation to determine the ODH Fatality Rate: $\Phi = 1.287 \times 10^{-7}$. Determine the ODH Classification for this rate.

This lab would be an ODH 1 area, and require the controls listed in the section 10 table.

In an actual assessment, the fatality rate for all failure modes and ODH sources must be calculated. Factors such as ventilation, power failure, and human error are also addressed in the full assessment. The sum of the fatality rates for all failure modes determines the ODH area classification.

Room volume					
Room dimensions	length'	width'	height'	volume (ft ³)	Room volume (L)
	24	18	10	4320	122330

List of gas sources							
Quantity of LN ₂	liters liquid	liters gas	% of room volume	resulting % O ₂ (open vent room)	Fi	Pi	Φ
Example amount	100	69600	65.3967335	9.052016782	0.6433	0.0000002	1.286E-07 1
Quantity of LHe	liters liquid	liters gas	% of room volume	resulting % O ₂ (open vent room)	Fi	Pi	Φ
Example amount	50	37850	32.6983668	14.50242579	4.636E-05	0.0000002	9.272E-12 0

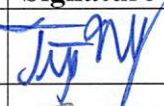
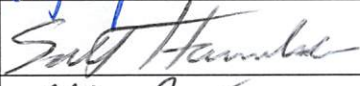

Total Φ	
1.28685 E-07	ODH Class
	1

18.0 REVISIONS AND APPROVALS:

Revisions

Date	Revision #	Section	Description
2/19/2018	2	All	Document Revision: General information updated. Appendixes added. ODH Review information and materials. Fixed and personal monitor updates.
8/22/2018	2	All	Final edit revision 2

Approvals

Title	Reviewer	Signature
Director: DC User Program	Tim Murphy	
Assistant Lab Director: DC Instrumentation/Operations	Scott Hannals	
Hybrid & Cryogenic Operations:	Mark Vanderlaan	
Associate Director: Environmental Health & Safety	Laymon Gray	