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Cryogenic Safety at Esrange Space Center

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1 PREFACE

1.1 Purpose

This directive establishes requirements for minimizing cryogenic hazards to personnel, hardware, and facilities at the Esrange Space Center (ESC). It also describes the controls and measures implemented by ESC to assess and mitigate the hazards associated with cryogenic systems, such as over-pressurization, frostbite, and potential oxygen-deficient areas.

1.2 References

ASTM G63-15: Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service

ASTM G88-13: Standard Guide for Designing Systems for Oxygen Service

ASTM G94-05(2014): Standard Guide for Evaluating Metals for Oxygen Service

ASTM MNL 36: Guidelines for Oxygen System Design

Esrange Safety Manual

NFPA 55: Compressed Gases and Cryogenic Fluids

1.3 Definitions

Cryogenic – Operating at or below -150 °C or 123° K.
Cryogenic System – An item of equipment or multiple items operating together that contain at least one component that operates at cryogenic temperature. Closed cycle refrigerators or cryo cooler setups are examples of cryogenic systems.
Dewar – A glass or metal container that may have an annular vacuum space for thermal isolation, which is used especially for storing components or gases at cryogenic temperature.
Oxygen Deficient Atmosphere – Occupational Safety and Health Administration (OSHA) defines an oxygen deficient atmosphere as one having less than 19.5% oxygen by volume
Qualified Personnel – Having sufficient knowledge, expertise and training required to complete a task, as deemed by the authority responsible for safe operations of the equipment with which that task is associated.

1.4 Acronyms

COTS	Commercial Off the Shelf
CSB	Cryogenic Safety Board
ESB	Esrange Safety Board
ESC	Esrange Space Center
ESM	Esrange Safety Manual
GHe	Gaseous Helium
GN_2	Gaseous Nitrogen
LHe	Liquid Helium

LN_2	Liquid Nitrogen
LO_2	Liquid Oxygen
ODH	Oxygen Deficiency Hazard
OJT	On the Job Training
PPE	Personal Protective Equipment
SSC	Swedish Space Corporation

2 ROLES AND RESPONSIBILITIES

In this document, a requirement is identified by "shall," a good practice by "should," permission by "may" or "can," expectation by "will" and descriptive material by "is."

2.1 Esrange Safety Board

ESB shall:

a. Oversee overall direction of the Cryogenic Safety Program.
b. Designate the Chair of the Cryogenic Safety Board (CSB);

2.2 Line Managers

Line managers shall:

a. Designate custodians of cryogenic systems and Oxygen Deficiency Hazard (ODH) designated areas;
b. Maintain a record of individuals trained on any cryogenic system;
c. Identify persons capable of providing the on the job training (OJT) specified in this document and, upon request of the CSB provide justification that said persons are qualified to administer this training;
d. Ensure that all facilities and equipment are properly maintained;
e. Ensure that applicable employees are trained and knowledgeable in the hazards associated with cryogenic systems and potential oxygen deficiency;
f. Ensure that cryogenic safety requirements are in place on dewars used by their organization but owned by another organization;
g. Ensure potential ODH areas are analyzed and classified accordingly;
h. Ensure that hazard warning signs required by this directive are procured and posted by the user organization under the guidance of the CSB; and
i. Ensure that oxygen monitors within their jurisdiction are maintained and calibrated as defined by the manufacturer.

2.3 Cryogenic Safety Board

The CSB will consist of representatives identified by line managers who own cryogenic systems or the Ground Safety Officer as having varying areas of expertise. The CSB is responsible to the ESB and shall:

a. Oversee implementation and maintenance of ESC's Cryogenic Safety Program, part of which is the ODH program;
b. Meet when necessary, to accomplish its responsibilities;

c. Ensure that the cryogenic safety program at ESC minimizes the health and safety risks to people, hardware and facilities;
d. Halt any cryogenic operation if the requirements of ESM are not met.
e. Review and approve new or altered cryogenic systems prior to their first operation for adherence to the requirements described in section 4.1 and, if necessary, prescribe conditions and requirements to minimize cryogenic hazards. The CSB may designate a person or persons to give approval for routine requests;
f. Review and approve ODH calculations as per section 9.1;
g. Review all cryogenic areas prior to startup of operations and after each approved alteration;
h. Specify posting and entry requirements for entry into designated ODH areas;
i. Develop and maintain the cryogenic working group charter; and
j. Develop and maintain an inventory of all cryogenic systems and ODH designated areas at ESC.

2.4 The Chair of the CSB shall:

a. Be appointed by the ESB for a term of 2 years;
b. Convene the CSB as necessary to meet the requirements of this document;
c. Maintain a record of CSB attendance and meeting minutes;
d. Act on behalf of the CSB as necessary.
e. Audit cryogenic safety records and evaluate compliance with CSB requirements;
f. Maintain appropriate records of inspections and evaluations;
g. Require the immediate cessation of operations of any cryogenic systems or ODH area determined to pose an imminent threat to personnel safety; and
h. Conduct periodic inspections of cryogenic or ODH areas for compliance to this document and to industry standards for cryogenic safety.

2.5 Users/Custodians

Users work directly with cryogens or cryogenic systems. Custodians are users who have primary responsibility for a cryogenic system:

a. All users of cryogens shall take the required cryogenic training described in this document and follow the directives and instructions described herein;
b. Custodians shall ensure that cryogenic safety hazards are reduced to as low a level as is reasonably achievable. This includes scheduling a safety analysis and review of their systems prior to first operation as described herein;
c. Custodians shall ensure alterations to any previously reviewed system which could possibly impact worker safety are reviewed by the CSB; and
d. Custodians shall ensure that all safety documentation is updated and consistent with the operating system it is associated with and be prepared to demonstrate this to the CSB upon request.

2.6 Ancillary Personnel

Ancillary personnel work in the immediate vicinity of cryogens or cryogenic systems but do not work directly with them. They may also be personnel required to enter ODH designated areas as part of their normal work duties. Examples are security or custodial workers. Ancillary personnel shall take the required ODH and/or cryogenic training described in this document and follow the directives and instructions therein.

2.7 Contractor and Guest Cryogenic Operators

Contractors and other personnel operating at ESC facilities are subject to all provisions of the ESC Cryogenic Safety Program. Contractors may be exempt from training requirements if their cryogenic training program is reviewed and approved by the CSB.

3 HARDWARE REQUIREMENTS

3.1 Commercial Off the Shelf (COTS) Products

COTS items shall be clearly designated for use at cryogenic temperatures. These items shall be used in strict accordance with manufacturer's specifications and operated as described in this document. Any modification to a COTS item is subject to review by the CSB as described herein.

3.2 Custom Fabricated Equipment

Custom fabricated equipment which will operate at cryogenic temperature shall be designed and constructed in accordance with good cryogenic safety practices and made as safe as practicably possible. Pressure vessels shall conform to ESM. All specifications for custom fabricated equipment shall be reviewed by the CSB (or designee), and all operating cryogenic systems shall be reviewed by the CSB as set forth in this document. The responsible experimenter is required to supply any applicable safety documentation described in the CSB review section (4.1).

3.3 Legacy Systems

Operating legacy cryogenic systems shall meet all applicable cryogenic safety requirements and be brought into compliance with current standards as much as practicable. Safety aspects of any exception to current standards shall require a waiver as per ESM and shall be reviewed in detail by the CSB.

3.4 Loaned Cryogenic Equipment

When equipment is on loan from another branch/organization, the safety responsibility lies in the branch/organization using the borrowed equipment. This includes ensuring that a safety peer review process (see Section 4.0) is done if any substantial changes are made to the initial system safety documentation. The branch/organization lending the equipment is obligated to provide any necessary instruction and documentation to support safe operation of that equipment. This

includes but is not necessarily limited to: equipment documentation, operating procedures, maintenance requirements, and OJT.

4 CSB PEER REVIEWS

To verify compliance with ESC cryogenic safety requirements, cryogenic equipment and systems shall be subjected to a safety review by the CSB prior to their first operation. Reviewed systems shall not operate without formal approval from the CSB.

4.1 CSB Review Documentation

At least 1 week prior to first operation of any cryogenic system, all of the following applicable documents shall be supplied to the CSB as part of the peer review process:

a. Schematics and piping and instrumentation flow diagrams as required providing a complete and accurate functional description of the system;
b. Sufficient documentation to show that the components and materials used are appropriate for cryogenic temperatures;
c. A description of operating procedures;
d. A description of any necessary operator training;
e. A list of all valves and ports which have the potential of discharging cold gas or cryogens to the atmosphere (the possibility of such a discharge causing personnel injury should be evaluated);
f. A description of any maintenance requirements;
g. An analysis demonstrating the adequacy of pressure relief valve sizing under worst-case failure conditions; and
h. A completed ODH analysis evaluating the risk presented under worst-case failure conditions. See Section 9.1.
i. A risk and consequences analysis on the entire system.

The CSB may request additional documentation unique or specific to any cryogenic system under review.

4.2 CSB Review Process

The chair of the CSB shall convene the group and meet with the responsible system operator after reviewing the safety documentation package. The CSB shall also conduct a walkthrough of the cryogenic test setup prior to operations to ensure safety requirements are met. Periodic safety audits, occurring no less than annually, of operating cryogenic systems shall be conducted to ensure that safety documentation is consistent with the operating system with which it is associated. Any operating system configuration change that significantly alters the safety documentation requires review and approval by the CSB.

5 PERSONAL PROTECTIVE EQUIPMENT (PPE)

Appropriate PPE is required when handling, transferring, or working with cryogenic fluids. PPE shall include:

a. Eye protection – Safety goggles are required when handling or transferring fluids which might result in exposure to cold boil off gases. Full face shield is recommended. Safety glasses with side shields are acceptable when working with closed cryogenic systems.
b. Hand protection – Safety gloves rated for use with cryogenic fluids are required when working with cryogens. Loose nylon insulating gloves are acceptable;
c. Clothing – Long-sleeved, non-absorbent shirts and non-absorbent long pants are acceptable. Shorts or skirts that can potentially expose bare skin are not permitted. Lab coats or aprons are recommended; and
d. Footwear – Non-absorbent footwear is required. Sandals or open-toed shoes are not permitted.

6 TRAINING OF CRYOGENIC PERSONNEL

6.1 Training Requirements

All personnel working with cryogenic fluids shall be thoroughly familiar with the hazards involved. They shall also be familiar with all emergency measures that may be required in the event of an accident. Thus, all employees who work in potential ODH areas shall take ODH training and all persons working with or in proximity to cryogenic fluids shall take general hazards training. Any persons involved in the design or procurement of cryogenic components, hands-on use of sub-atmospheric liquid helium systems, or liquid oxygen (except personnel strictly associated with administrative or procurement aspects) are required to take additional training covering the associated safety aspects. Finally, each employee shall be given OJT specific to any cryogenic equipment or system he or she is expected to use. Table 1 summarizes cryogenic training requirements. Any contractor organization that has an equivalent training program may be exempt from these training requirements with approval of the CSB. ODH training is required to be taken at 2-year intervals.

Table 1. Training requirements.

	ODH	Basic hazards	Design, construction and operations	OJT
Entry into ODH Designated Areas	X			
Working with or around cryogens, basic use of LN2, or LAr or LHe	X	X		X
Cryo system designers, liquid oxygen users, hands on operators of sub-atmospheric LHe dewars	X	X	X	X

6.2 Dewar User OJT Requirements

Prior to operation on any cryogenic systems, users shall be instructed in the following:

a. Description of the equipment;
b. Operating procedures including PPE requirements;
c. Maintenance schedule and procedures;
d. Hazards specific to the particular test setup;
e. Location of ODH alarms and routes of egress in the event of an alarm; and
f. Procedures for reporting of incidents.

It is the responsibility of the line manager to ensure that persons administering OJT are duly qualified. Requests for qualifications for OJT trainers may be made by the CSB. OJT group certification is possible on a series of dewars if they are similar in hazards, design and operations.

Training shall be documented and records kept within respective branches. The documentation shall include: 1) content of training, 2) date, 3) name of trainer, and 4) a dated training attendance list showing names of the trainees and their signatures. The CSB may request to review user certification documentation for any operating cryogenic system.

6.3 User Certification for Liquid Nitrogen Filling Stations

All users of liquid nitrogen filling stations shall be certified on that particular station. The certification process shall require:

a. A review of the fill procedure, including any PPE requirements;
b. A description of the dewar inspection process as prescribed by the CSB;
c. An explanation of the emergency procedures associated with cold contact burns and frostbite; and
d. A demonstration of the filling process by the user.

Users of liquid nitrogen filling stations need to be recertified if a modification is made to the filling station which effects its operation or potential hazards.
All stations shall have the name of responsible trainers and an operating procedure posted. It is the responsibility of the branch or organization owning the filling station to designate a responsible person and to maintain a record of certified users for each station. The responsible person for a LN2 filling station shall be the primary certifier for new users at that station and shall ensure that safety postings are maintained and an up to date operating procedure is available.

7 SYSTEM MAINTENANCE AND INSPECTION

Cryogenic systems and equipment shall be maintained by qualified personnel to ensure safety. Maintenance shall be conducted as per equipment manufacturer. The schedule and nature of the maintenance shall be recorded as part of the safety documentation listed in section 4.1. Dewars shall also be inspected monthly for unusual or excessive ice buildup, which can potentially block relief paths or may be a sign of a compromised insulating vacuum.
In addition to periodic in-service inspections cryogenic systems and equipment shall be inspected by the operator prior to and during system operations and after system shutdown. Inspection shall also take place after any unusual incident which might affect the integrity and safety of an item of cryogenic equipment.
Documentation of this maintenance shall be kept with the responsible organization.

8 LIQUID OXYGEN (LO_2) SAFETY

8.1 Applicable Standards

Because of the unique hazards associated with liquid oxygen, additional safety requirements are required to ensure safe operations.

8.1.1 Design Standards

LO_2 systems built, designed, or operated at ESC shall conform to either: ASTM MNL 36: Guidelines for Oxygen System Design, Material Selection, Operations, Storage, and Transportation or all applicable of the following:

a. ASTM G88-13: Standard Guide for Designing Systems for Oxygen Service;
b. ASTM G63-15: Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service;
c. ASTM G94-05(2014): Standard Guide for Evaluating Metals for Oxygen Service;

8.1.2 Cleanliness Standards

LO_2 systems or components shall be cleaned in accordance with: ASTM G93-19: Standard Practices for Cleaning Methods for Materials and Equipment Used in Oxygen enriched Environments.

8.2 LO_2 Storage

8.2.1 Fixed or Permanent Storage

Fixed or permanent LO_2 storage requirements are determined by the amount of cryogen stored. Breaking point is at 500 kg.

a. LO_2 storage that is less than 500 kg of LO_2 shall be stored in accordance with NFPA 55: Standard for the Storage, Use, and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders, and Tanks.
b. LO_2 storage that is more than 500 kg of LO_2 shall be stored in accordance with: NFPA 55 Standard for Bulk Oxygen Systems.

8.2.2 Portable Dewar Storage

a. All temporary oxygen dewars shall be separated from flammables and combustibles by a minimum of 6 m. "No Smoking" and "No Open Flames" signs are to be posted at the storage location.
b. Smoking and open flame are prohibited within a minimum of 6 m of any oxygen dewar or purge system.
c. LO_2 dewar storage areas shall have fixed monitoring for high oxygen levels. These monitors shall alarm at 21.5% oxygen by volume.

8.3 User Certification for Liquid Oxygen Systems

All users of LO_2 shall be certified. The list of OJT-required topics described in section 6.2 shall be expanded to include:

a. An explanation of oxygen material compatibility issues;
b. Combustion/flammability issues associated with LO_2 dewar storage areas;
c. A description of the hazards of high flow velocities in oxygen systems;
d. A description of the cleanliness requirements for oxygen systems; and
e. Proper procedures for handling leaks and spills.

Certification records for liquid oxygen purchasers and users shall be kept by the responsible line manager.

8.4 CSB Review Process for LO_2 Systems

Any system using liquid oxygen shall be reviewed by the CSB. For any LO_2 system review the following shall be added to the list of required safety documentation described in section 4.1:

a. Identification of designated dewar or bulk LO_2 storage areas;
b. A plan for mitigation of combustion hazards;
c. Analysis of material compatibility with O_2;
d. Cleanliness procedures;
e. Analysis of piping design for minimization of flow velocities; and
f. Electrostatic discharge risk mitigation plan.

9 OXYGEN DEFICIENCY HAZARD (ODH)

9.1 ODH Risk Assessment

An ODH assessment shall be conducted whenever an area containing enough displacing gas to pose a potential oxygen deficiency is established or modified, and whenever cryogens are used, stored, or dispensed. The goal of the ODH risk assessment is to estimate the increase in the rate at which fatalities will occur in a given area so that appropriate controls can be established to mitigate the hazard. The level of risk is based on the volume of cryogen in a given area as well as the expected component failure rates for the cryogenic or other equipment that presents an oxygen deficiency hazard. The CSB shall designate the proper procedure for assessing the ODH of a given area as well as the proper ODH alarm response procedure.

Personnel shall not enter or occupy an area where the oxygen level is less than 19.5% by volume.

9.2 ODH Postings

Areas determined to have a potential for oxygen deficiency shall be identified by postings. All entrances shall be posted. Persons authorized by the CSB can post and de-post areas if the hazard is temporary and an ODH analysis considering the

change in potential displacing gas has been made. The ODH alarm response policy, as determined by the CSB, shall be posted adjacent to any fixed ODH alarm sensor or at the entrance to any ODH designated areas while the ODH threat is present.

9.3 Visitor Requirements

Visitors or temporary workers who have not had ODH training may enter a posted ODH area ONLY after the ODH has been explained to them by personnel familiar with the hazards in the area and who have themselves taken the ODH training course. Visitors may not enter specially designated high hazard ODH areas without taking ODH training and following all CSB requirements.

9.4 Oxygen Monitoring

9.4.1 Fixed Monitors

Fixed Oxygen monitors shall alarm at an oxygen concentration of 19.5% and have a siren and flashing strobe light. The siren and strobe shall be distinctive from other alarms in the immediate area, such as fire alarms. Oxygen monitors shall be installed with consideration of the buoyancy of the displacing gas. Fixed oxygen monitors shall not be disabled except by qualified personnel, in conjunction with the CSB.

9.4.2 Personal Oxygen Monitors

Personal oxygen monitors shall be available adjacent to ODH designated areas. Portable oxygen monitors will alarm at 19.5% oxygen. The organization issuing personal oxygen monitors is responsible for compliance with this requirement.

9.4.3 Maintenance and Calibration of Stationary and Portable Monitors

Monitors shall be calibrated in accordance with the manufacturer’s recommendations, but not less than annually. Calibration shall be done using a known sample gas, which shall verify the alarm set point of 19.5 %. Personal oxygen monitors shall not be used beyond the date they are due for recalibration. If past due, the monitor shall be returned to the organization that issued it for recalibration.