



Department of the Air Force
HQ AEDC (AFMC)
Arnold AFB, TN 37389

Safety, Health, and Environmental Standard

Title: CRYOGENIC FLUIDS
Standard No.: E13
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The provisions and requirements of this standard are mandatory for use by all AEDC personnel engaged in work tasks necessary to fulfill the AEDC mission. Please contact your safety, industrial health and/or environmental representative for clarification or questions regarding this standard.

Approved:

Contractor /ATA Director
Safety and Health Group

Air Force Functional Chief



Safety, Health, and Environmental Standard

CRYOGENIC FLUIDS

1.0 INTRODUCTION/SCOPE/APPLICABILITY

1.1 Introduction

1.1.1 This standard outlines general safety criteria applicable to activities involving cryogenic operations at AEDC.

1.2 Scope

1.2.1 This standard implements and explains the process for cryogenic activities. The intent of the standard is to limit the exposure of personnel when conducting cryogenic operations, consistent with safe and efficient operations. When there are any conflicts noted between this standard and industry or national codes, standards or regulatory requirements, the operating contractor shall notify the government.

1.3 Applicability

1.3.1 This standard applies to all personnel at AEDC whose responsibilities and activities involve performing work, services, support, transportation, or test activities involving cryogenics.

2.0 BASIC HAZARDS/HUMAN FACTORS

Cryogenic operations produce numerous hazards. The primary ones are burns, frostbite, asphyxiation, burst piping from trapped liquid, high pressures, and flammability.

3.0 DEFINITIONS

Cryogenic Fluids - Substances that exist only in the vapor phase above -100°F (-73°C) at one atmosphere pressure. Properties of cryogenic fluids are presented in Annex A.

Dewars - Insulated storage tanks designed specifically to store cryogenic fluids.

Operating Contractor - A base contractor directly accountable to the Air Force for the AEDC mission. This is the term used to identify the AEDC Operation, Maintenance, Information Management and Support Contractor.

Outside Contractor/Subcontractor - An organization employed by a contractor or the Air Force to do construction, maintenance, repair or other work at AEDC. There is no employment relationship, control or supervision of the subcontractor's employees by AEDC contractors. Also referred to as the construction contractor.

Pressure Relief Devices - Used to vent pressure buildup in a system if it exceeds a pre-determined amount.

4.0 REQUIREMENTS/RESPONSIBILITIES

4.1 Requirements

If cryogenics are being used as a rocket propellant, then explosives safety training is required.

4.1.1 Pressure Buildup and Relief

4.1.1.1 Heat flux into the cryogen is unavoidable, regardless of the quality of the insulation provided. Pressure relief must be provided to permit routine off-gassing of the vapors generated by this heat input. Typically spring-loaded relief devices or an open passage to the atmosphere is used to provide relief.

4.1.1.2 Additional relief devices should be provided as backup to the operational relief and when the capacity of the operational relief device is not adequate to take care of unusual or accident conditions. This may be the case if the insulation is dependent on the maintenance of vacuum in any part of the system (this includes permanently sealed dewars), if the system may be subject to an external fire, or if rapid exothermic reactions are possible in the cryogen or a container cooled by the cryogen. In each case, relief devices

capable of handling the maximum volume of gas that could be produced under the most adverse conditions must be provided. Frangible disks are recommended for this service.

- 4.1.1.3 Each portion of the cryogenic system must have uninterruptible pressure relief. Any part of the system that can be valved off from the remainder must have separate and adequate provisions for pressure relief. Examples of parts that usually require separate relief systems include: pressurized supply dewars; tubing and hoses used to transfer cryogen unless an air gap is provided; bath space surrounding experimental volume; experiment volume, even if cryogen is not present; and vacuum spaces in contact with cryogen. Pressure-relief devices must be provided in the last two cases since cracks may develop at cryogenic temperatures. Cryogen or air may leak into sealed spaces through such cracks. Air condenses at least partly under such conditions and exists as a cryogen in the sealed space as well. Upon warming, these cracks may close, and the contained vaporizing fluid then can rupture the vessel.
- 4.1.1.4 All parts in contact with the fluid must be rated for cryogenic service. While some economies can be achieved by using ordinary pressure system parts on sections that are thermally isolated from the fluid, this practice is advisable only when performed by an engineer experienced in design of cryogenic systems.
- 4.1.1.5 If dry ice or a dewar containing cryogenic fluid must be transported by elevator, it should not be accompanied by personnel. In case of power failure, an excessive amount of cryogen could vaporize and escape into the cab, leaving personnel with no means to escape or ventilate the cab. Instead, the load should be sent by itself and measures taken to ensure that no passengers are loaded on intervening floors.
- 4.1.1.6 Cryogenic dewars must be rated for cryogenic service. Coffee-type thermos containers and other devices not specifically rated for cryogenic service shall not be used for cryogenic storage or use.

4.1.2 Labeling and Posting

Storage dewars, process vessels, piping, etc., shall be labeled with the common name of the contents. Where a flammable cryogenic or liquid oxygen is used, "DANGER, NO SMOKING" signs shall also be posted. In many cases, it is also required to post emergency instructions, emergency call numbers, etc.

4.1.3 Liquid Oxygen

- 4.1.3.1 Liquid oxygen shall only be handled by personnel who are properly trained and appreciative of the hazards. Liquid oxygen contains 4,000 times more oxygen per unit volume than the atmosphere. Materials that are normally considered to be noncombustible burn rapidly in the presence of liquid oxygen, and organic materials react explosively. Hydrocarbon surface contamination levels must be kept to less than 100 milligrams per square foot (1.06 mg/cm^2) to avoid detonation within the system. Additionally, liquid oxygen has a high heat capacity, and spills can penetrate deeply and persist for extended periods of time, causing fires and explosions long after the visible spill has completely disappeared.
- 4.1.3.2 Liquid oxygen should only be handled over surfaces known to be suitable for such purposes, such as concrete or clean gravel. Accidental spills onto asphalt, plastic, wood or other organic substances can result in detonation of the surface. Repeated spills multiply the hazard. Immediate flushing with water is advised to increase the evaporation rate after a spill.
- 4.1.3.3 Exposure to concentrated oxygen gas persists in the clothing and hair for long periods of time. Exposure to ignition sources, such as smoking and electrostatic discharge, may result in severe clothing fires and must be avoided during and after handling of liquid oxygen.
- 4.1.3.4 Similar precautions should also be employed when cryogenics containing liquid oxygen as a component are encountered. Even a slight change in oxygen concentration from the atmospheric proportions alters burning characteristics of materials substantially.
- 4.1.3.5 Liquefied oxygen storage systems and operating locations will be placarded to indicate: "OXYGEN-NO SMOKING-NO OPEN FLAMES."
- 4.1.3.6 When used as a propellant, liquefied oxygen must meet the criteria for liquid propellants.

4.1.4 Air-Freezing Cryogenics

- 4.1.4.1 Certain cryogenics, such as helium and hydrogen, are cold enough to solidify atmospheric air. Entry of air into such cryostats must be prevented by pressurizing the system. If openings to the atmosphere exist, they

are likely to become plugged by solidified air, leading to over pressure and vessel failure if they are relied on for pressure relief. Such a condition also results in hazardous contamination of the fluid. Again, adequate pressure-relief devices must be provided to vent gas produced in case of maximum possible heat flux into the system.

- 4.1.4.2 Unless these fluids are handled in vacuum-jacketed vessels and piping, air also condenses on the exterior of the system. Due to the different evaporation temperatures, condensate is rich in oxygen content. The hazards created by this include frostbite from touching the cold surfaces, dripping liquid air (oxygen enriched), and exploding insulation. The latter can happen when air condenses between the metal surface and the insulating layer. On warming, the air vaporizes and can rip off the insulation with explosive force. Such insulation systems must be specifically engineered to prevent air penetration.

4.1.5 Liquid Hydrogen

- 4.1.5.1 Liquid hydrogen poses extreme hazards if not handled correctly. Its use shall be limited to specially trained personnel. The hazards arise not only from the air-freezing cryogen itself, but also from the hydrogen gas that is generated in large volume if the fluid leaks or spills.
- 4.1.5.2 Hydrogen expands 850 times in volume upon vaporization. Flammable mixtures with air are formed over a wide range of concentrations, approximately 4 to 75% by volume. It can be ignited by a spark containing only 0.02 millijoules of energy; the minimum energy requirement to ignite methane in air is 15 times larger. Furthermore, explosion-proof electrical equipment for hydrogen service is often not available; custom-designed electrical systems based on thorough understanding of the properties of hydrogen are required. Finally, hydrogen causes embrittlement of materials otherwise suitable for cryogenic service.
- 4.1.5.3 As a minimum, liquefied hydrogen systems will comply with the following requirements:
- 4.1.5.3.1 Each container shall be legibly marked to indicate “LIQUEFIED HYDROGEN – FLAMMABLE GAS”.
- 4.1.5.3.2 Liquefied hydrogen containers shall be equipped with safety relief devices.
- 4.1.5.3.3 Liquefied hydrogen storage containers shall not be exposed by electric power lines, flammable liquid lines, flammable gas lines, or lines carrying oxidizing materials.
- 4.1.5.3.4 Liquefied hydrogen storage containers and associated piping shall be electrically bonded and grounded.
- 4.1.5.3.5 Storage sites shall be fenced and posted to prevent entrance by unauthorized personnel. Sites shall be placarded as follows: “LIQUEFIED HYDROGEN –FLAMMABLE GAS-NO SMOKING-NO OPEN FLAMES”.
- 4.1.5.3.6 When used as propellant, liquefied hydrogen must meet the criteria for liquid explosive propellants.

4.1.6 Oxygen Enrichment

- 4.1.6.1 Cryogenic fluids with a boiling point below that of liquid oxygen have the ability to condense oxygen out of the air if exposed to the atmosphere. This is particularly troublesome if a stable system is replenished repeatedly to make up for evaporation losses; oxygen accumulates as an unwanted contaminant. Violent reactions may occur if the system or process is not compatible with liquid oxygen.
- 4.1.6.2 Oxygen enrichment also occurs if liquid air is permitted to evaporate. Oxygen evaporates less rapidly than nitrogen. Oxygen concentrations of 50 percent may be reached. Condensed air dripping from the exterior of cryogenic piping is enriched in oxygen.

4.1.7 Personal Protective Equipment

- 4.1.7.1 The use of safety glasses is required at all times when cryogenic fluids are present. If a cryogen is poured or if the fluid is in an open container it may bubble, the use of safety goggles and a full-face shield is required. Safety glasses and face shield are required when valves are actuated on piping systems, etc., unless the operator is shielded from leaks at potential failure points.
- 4.1.7.2 Hand protection is primarily required to guard against the hazard of touching cold surfaces. Loose insulating gloves, rated for cryogenic use, that can be tossed off readily in case they become soaked with cryogen are required.

- 4.1.7.3 Cryogen handlers shall wear leather boots and cuff-less trousers extending over the boot. The leather steel toe boot shall be approximately 8 inches in height with close fitting top and neoprene sole and heel.
- 4.1.7.4 Industrial clothing made of non-absorbent material is usually satisfactory. An apron rated for cryogenic use is required when quantities of cryogen are handled and there is a credible risk of splashing. Where exposure to drenching is possible, a full protective suit with supplied air should be considered. However, the system should be engineered to prevent the possibility of such an exposure.

4.1.8 Mechanical/Chemical

- 4.1.8.1 Since cryogenic fluids exist as liquids only at temperatures considerably below ambient, normal storage and fluid containment must allow for the unavoidable heat input from the environment. For ordinary operations, this means good insulation, adequate pressure-relief devices, and proper disposal or recycling of the gases that are continually produced. Full containment of the fluid as a liquid at room temperature is usually not feasible; e.g., the pressure required to maintain helium at liquid density at room temperature is 18,000 psi, for hydrogen is 28,000 psi, and for nitrogen is 43,000 psi.
- 4.1.8.2 The chemical properties of substances are severely exaggerated under cryogenic conditions. Liquid oxygen, for example, reacts explosively with materials that are usually considered to be noncombustible. Nitric oxide is detonable under cryogenic conditions, a fact that is not widely recognized; a detonation can be set off by "bumping" or by organic impurities. It must be remembered that condensing a cryogen from a pure gas at room temperature concentrates the material typically 700 to 800 fold; in the case of neon, the concentration is over 1,400 fold.
- 4.1.8.3 Material properties are drastically affected by cryogenic temperatures; ductile materials become brittle, material shrinkage exceeds anticipated values; leaks can develop that are not detectable at room temperature even under considerable pressure, etc. Hence, the suitability of materials must be carefully investigated before they are employed in cryogenic service.

4.1.9 Adverse Weather Conditions

The AEDC Operations Center is responsible for making initial notification of severe weather conditions, especially thunderstorms and lightning. Operations involving explosive, flammable cryogenics shall be discontinued if lightning is detected within ten miles. Operations involving non-explosive or flammable cryogenics will have adverse weather conditions analyzed and documented in a system safety hazard analysis for countermeasures, and procedures posted to cover adverse weather conditions.

4.1.10 Procedures

- 4.1.10.1 Cryogenic fluids shall be handled only by personnel fully aware of the properties of the materials and equipment, and responsibly cognizant of the consequences of a mishap. Operators should be selected on the basis of capability to understand the hazards and the equipment, mature judgment, and ability to follow established procedures.
- 4.1.10.2 Cryogenic work must be performed according to standard operating procedures developed by competent operating personnel and reviewed by the contractor safety office. Checklists, valve sequences, etc., should be included. Deviations from established procedures should be allowed only after evaluation of the consequences and with the consent of higher authority. Procedures should be reviewed periodically and updated whenever changes in procedures or equipment are made.
- 4.1.10.3 An emergency plan to guide personnel actions during malfunction or mishap is required. The plan should cover shutdown, alarm, and evacuation procedures for likely mishaps. Plans that cover every possible exotic mishap are likely to be disregarded entirely. Periodic review of such a plan by operating personnel is essential to its effectiveness. For large installations, liquid oxygen or liquid hydrogen operations, etc., periodic drills and department orientations must be included in emergency procedures.

4.2 Responsibilities

4.2.1 Contractor Responsibilities

Ensure that all personnel whose duties involve contact with cryogenics are trained and qualified to perform their designated tasks.

4.2.2 Operating Contractor Safety Office Responsibilities

- 4.2.2.1 Assist in the development and implementation of required cryogenic safety procedures and advise contractor personnel on all matters involving cryogenics.
- 4.2.2.2 Monitor cryogenic operations to ensure compliance with safety criteria. Special emphasis should be placed on operations involving liquefied hydrogen and oxygen operations.
- 4.2.2.3 Inspect each cryogenic operation or location at least annually; perform spot inspections as necessary, document inspection findings, assign Risk Assessment codes, and ensure that satisfactory corrective actions are implemented. Forward a copy of each inspection report and subsequent corrective actions to AEDC/SE.
- 4.2.2.4 Monitor personnel who handle, inspect, transport, or maintain cryogenic liquids to help ensure they receive required cryogenic safety training.
- 4.2.2.5 Support Operations in initial and three-year refresher cryogenics safety training.

4.2.3 Operating Contractor Functional Manager and/or Project Engineer Responsibilities

- 4.2.3.1 Ensure that system safety analyses are performed for all projects involving cryogenics. These analyses should identify hazards, associated risks, and specific controls to be implemented to eliminate or reduce those risks.
- 4.2.3.2 Ensure that operating instructions/procedures and emergency instructions/procedures are developed and posted for all cryogenic operations as applicable.
- 4.2.3.3 Ensure that all personnel who handle, inspect, transport, or maintain cryogenics receive required cryogenics safety training prior to handling/working with them. Training shall include basic cryogenics training provided by the operating contractor safety office and operational specific cryogenics training provided by the operational department.

4.2.4 Operating Contractor Supervisor Responsibilities

- 4.2.4.1 Be knowledgeable of all hazards involved in the operation, convey emergency procedures to workers and visitors, and maintain strict housekeeping standards. The supervisor shall also know what steps to take when abnormal conditions arise.
- 4.2.4.2 Ensure that tasks involving cryogenics are performed by qualified personnel in the manner prescribed in this standard, and other applicable safety directives.
- 4.2.4.3 Brief all personnel on the standards they are expected to follow and the hazards of each cryogenic operation.
- 4.2.4.4 Ensure that approved operating instructions/procedures are posted or readily available for each cryogenics operation.
- 4.2.4.5 Maintain good housekeeping practices within cryogenic storage and operating areas.
- 4.2.4.6 Ensure that smoking locations are designated as needed in operating areas and are approved by the AEDC Fire Department.
- 4.2.4.7 Ensure that all permanently installed grounding, bonding, conductive surfaces, and lightning protection systems in cryogenic flammable/explosives areas are inspected and tested as scheduled.
- 4.2.4.8 Maintain copies of the grounding/bonding/lightning protection test reports from Facilities O&M Utilities Systems Engineering.
- 4.2.4.9 Ensure personnel have received initial, area/operational specific, and three-year refresher, cryogenics safety training and are briefed on specific hazards prior to handling/working with cryogenics.
- 4.2.4.10 Verify completion of training for personnel handling and/or working with cryogenics.

4.2.5 AEDC Fire Department Responsibilities

- 4.2.5.1 Maintain a ready fire-fighting capability for fires involving flammable/explosive cryogenics.
- 4.2.5.2 Provide information on the fire characteristics of flammable/explosive cryogenics, as requested.
- 4.2.5.3 Exercise approval authority for all requests for smoking locations in and around flammable/explosives cryogenic areas.

4.2.6 **Operating Contractor Facilities O&M (Operations and Maintenance), Utilities Systems Engineering, Responsibilities**

- 4.2.6.1 Inspect and test electrical protection systems (grounding, bonding and lightning protections systems) in **cryogenic**/explosives areas annually.
- 4.2.6.2 Ensure all permanently installed grounding, bonding, conductive surfaces, and lightning protection systems in **cryogenic**/explosives areas are inspected and tested annually.

5.0 **OPERATING CONTRACTOR TRAINING**

- 5.1 **Operating Contractor personnel** must receive initial, and area/specific **cryogenic** safety training before participating in cryogenic operations. They must also receive three-year refresher training. All training administered must be documented. Personnel who work with cryogenics must understand all safety standards, requirements and precautions that apply to their operations.
- 5.2 Operating Contractor Safety shall administer initial and three-year refresher training for all affected Operating Contractor employees. Operations shall develop, administer, and document site-specific training for operators of each system utilizing Process Safety Management (PSM) principles for systems that are affected by the PSM standard for highly hazardous chemicals.
- 5.3 Operating Contractor Safety provides basic cryogenics training. The operational area functional manager, project engineer, test engineer, or supervisor provides area and operational specific cryogenics training.

6.0 **INSPECTIONS/AUDITS**

Cryogenics equipment, transfer piping, and associated items are to receive an annual inspection, as well as a five-year in depth inspection. Relief valves in particular are to be inspected. This is in addition to the daily inspections performed by operational personnel when one of the cryogenic systems is charged. These inspections must be performed by a qualified Nondestructive Examination Level II inspector.

7.0 **REFERENCES**

Safety with Cryogenic Fluids, by M. C. Zabetakis, Plenum Press, New York, 1967

AEDC Safety, Health and Environmental Standards

- A4, System Safety
- D2, Pressure Vessels and Systems
- D3, Identification of Piping Systems
- E15, Explosives Safety

Air Force Manual (AFMan)

- AFMan 91-201, Explosives Safety Standards

Air Force Occupational Safety and Health Standard (AFOSHSTD) 91-501

- Air Force Consolidated Occupational Safety Standard

Compressed Gas Association (CGA)

- CGA S-1 Pressure Relief Device Standards – Part 1 – Cylinders for Compressed Gases
- CGA S-1 Pressure Relief Device Standards – Part 2 – Cargo and Portable Tanks for Compressed Gases
- CGA S-1 Pressure Relief Device Standards – Part 3 – Stationary Storage Containers for Compressed Gases

Occupational Safety and Health Administration (OSHA) Code of Federal Regulations (CFR)

- CFR 1910.103, Hydrogen
- CFR 1910.104, Oxygen
- CFR 1910.119, Process Safety Management of Highly Hazardous Chemicals

8.0 **ANNEX**

Properties of Cryogenic Fluids

Annex A

Properties of Cryogenic Fluids

Gas	Boiling Point, deg ^a				Volume Expansion to Gas	Flam-mable	Toxic	Specific Gravity of Gas (Air = 1)	Odor
	C	F	R	K					
1,1-Difluoroethylene	-83	-117.4	342.3	190.2	---	Yes	No ^c	---	Faint Ether
Acetylene	-84	-119.2	340.5	189.2	---	Yes	Yes	0.9073	Garlic
Argon	-185.7	-302.3	157.4	87.5	847 to 1	No	No ^c	1.38	No
Boron Trifluoride	-100.3	-148.5	311.2	172.9	---	No	Yes	2.37	Pungent
Carbon Dioxide	-78.5	-109.3	350.4	194.7	553 to 1	No	Yes	1.5289	Slight Pungent
Carbon Monoxide	-192	-313.6	146.1	81.2	---	Yes	Yes	0.9678	No
Chlorotrifluoromethane	-81.4	-114.6	345.1	191.8	---	No	Yes	Mild	
Deuterium	-249.5	-417.1	42.6	23.7	---	Yes	Radioactive		
Ethane	-88.3	-126.9	332.8	184.9	---	Yes	No ^c	1.047	No
Ethylene	-103.8	-154.8	304.9	169.4	---	Yes	No ^c	0.978	Sweet
Fluorine	-187	-304.6	155.1	86.2	888 to 1	No	Yes	1.312	Sharp
Fluoroform	-84	-119.2	340.5	189.2	---	No	No ^c	1.047	No
Helium-3	-269.9	-453.8	5.9	3.3	757 to 1	No	No ^c	0.137	No
Helium-4	-268.9	-452	7.7	4.3	757 to 1	No	No ^c	0.137	No
Hydrogen	-252.7	-422.9	36.8	20.5	861 to 1	Yes	No ^c	0.06952	No
HydrogenChloride	-85	-121	338.7	188.2	---	No	Yes	1.268	Pungent
Krypton	-151.8	-241.1	218.6	121.4	700 to 1	No	No ^c	2.818	No
Methane	-161.4	-258.5	201.2	111.8	578 to 1	Yes	No ^c	0.5544	No
Neon	-245.9	-410.6	49.1	27.3	1438 to 1	No	No ^c	0.6964	No
Nitrogen	-195.8	-320.4	139.3	77.4	696 to 1	No	No ^c	0.967	No
Nitrous Oxide	-89.5	-129.1	330.6	183.7	666 to 1	No	No ^c	1.63	Sweet
Oxygen	-183	-297.4	162.3	90.2	860 to 1	No	No ^c	1.1063	No
Ozone	-111.9	-169.6	290.1	161.3	---	Yes	Yes	1.658	Yes
Tetrafluoromethane	-128	-198.4	261.3	145.2	---	No	Yes	1.62	No
Tritium	-248	-414.4	45.3	25.2	---	Yes	Radioactive		
Xenon	-109.1	164.4	624.1	164.1	573 to 1	No	No ^c	4.53	No

^a 0 deg. K = -273.16C; - 459.69F.

^bSublimes.

^cNontoxic, but can act as an asphyxiate by displacing air needed to support life. As with most chemicals, even harmless materials can be toxic or poisonous if taken in sufficient quantities under the right conditions.