Ames Health and Safety Procedures and Guidelines Last Revised: 06/01/2004 Redacted: 07/12/2004

Chapter 15 – Cryogenic Safety (REDACTED)

15.1 Introduction

A cryogenic gas is defined as a refrigerated liquid gas having a boiling point below -130°F at atmospheric pressure. Cryogenic safety refers to the potential hazards in handling liquefied gases because they are extremely cold and can cause cold contact burns (by the liquid), frostbite or cold exposure (by the vapor), and suffocation because of the ability of the liquid to rapidly convert to large quantities of gas. There are special hazards related to particular cryogenic materials such as oxygen and hydrogen, and systems using these gases are required to follow Safety Standard for Oxygen and Oxygen Systems, NSS 1740.15, and Safety Standard for Hydrogen and Hydrogen Systems, NSS 1740.16. Sections 15.14.1 and 15.14.2 list properties and hazards of the more common liquefied gases.

The NASA Safety Training Center (NSTC) offers Course 313, Cryogenic Safety. It is designed to provide the student with an in-depth understanding of NASA, Occupational Safety and Health Administration (OSHA), and National Fire Protection Association (NFPA) requirements for the safe handling and usage of cryogenic fluids. This course provides an overview of the basic principles of cryogenic fluids and the hazards associated with their use. It is based on NASA and NASA Center cryogenic safety documentation integrated with OSHA, NFPA, and pertinent regulations and standards. It is designed for those who design, implement, and operate flight and ground based cryogenic systems, and those who supervise or have safety oversight/inspection responsibilities for operations involving cryogenic fluids. The target audience includes safety, reliability, quality, maintainability, and health professionals; as well as supervisors, cryogenic system design engineers, and anyone working around or with cryogenic systems.

15.2 Applicability

This manual is applicable to: (1) all Ames Employees; and (2) all persons and entities who agree in writing to comply with this manual.

15.3 Purpose

This chapter provides a summary of the hazards associated with the use of cryogenic gases, and the basic recommended practices to prevent mishaps. It details the responsibilities for the safe use and handling of cryogenic gases, and provides a list of reference materials that can be used for hazard assessments and system design.

15.4 Responsibilities

15.4.1 Supervisors (All Levels)

REDACTED

15.4.2 Safety, Health and Medical Services Division

REDACTED

15.4.3 Employees

REDACTED

15.5 Cold Contact Burns

15.5.1 Avoid Contact

1. Liquid, vapor, or low-temperature gas will produce effects on the skin similar to a burn. This will vary with temperature and exposure time. The eyes can be damaged by an exposure to cold gases too brief to affect the skin.
2. Stand clear of boiling and splashing cryogenic liquid and its issuing gas. Boiling and splashing always occur when charging a warm container or when inserting objects into the liquid. Always perform these operations slowly to minimize boiling and splashing. Whenever you handle cryogenic liquids, be sure there is a hose or a large open container of water nearby. Use a clean dry cloth on the body that is accidentally splashed with liquid.
3. Never allow any unprotected part of your body to touch uninsulated pipes or vessels that contain liquefied gases; the extremely cold metal may stick fast and tear the flesh when you attempt to withdraw from it. Use tongs to withdraw objects immersed in liquid, and handle the tongs and the object carefully. In addition to the hazard of burns or skin sticking to cold materials, objects that are soft and pliable at room temperature usually become very hard and brittle at the temperatures of these liquids, are very easily broken, and may shatter violently.

15.5.2 Personal Protective Equipment

1. Protect your eyes with a face shield (safety glasses without side shields do not give adequate protection).
2. Always wear gloves when handling anything that is, or may have been, in contact with cryogenic materials. Insulated gloves are recommended, but leather gloves may also be used. The gloves should fit loosely so that they can be thrown off quickly if liquid should spill or splash into them.
3. When handling cryogenic liquids in open containers, it is advisable to wear high-top shoes.
4. Trousers should be cuffless and be worn outside the shoes.

15.5.3 Treatment of Cryogenic Burns

1. Remove any clothing that may reduce the circulation to the frozen area. Remove patient to the Ames Health Unit or a hospital.
2. Frozen tissues are painless and appear waxy with a pallid yellowish color. They become painful, swollen, and very prone to infection when thawed. Therefore, do not rewarm rapidly if the accident occurs in the field and the patient cannot be transported to a hospital immediately. Thawing may take from 15 to 60 minutes and should be continued until the blue pale color of the skin turns pink or red. Medication is normally required to control the pain during thawing and should be administered under professional medical supervision.
3. If the frozen part of the body has thawed by the time medical attention has been obtained, do not rewarm. Under these circumstances, cover the area with dry sterile dressings with a large bulky protective covering.

15.6 Frostbite and Exposure

Individuals not suitably protected against low ambient temperatures often associated with cryogenic handling may suffer cold exposure, so far as their reactions and capabilities are concerned. Continued exposure can result in frostbite. In this case there is sufficient warning by local pain while the freezing action is taking place. Rewarming at slightly above body temperature generally will prevent injury.

15.7 Physiological Effects

15.7.1 Effects of Cold on Lungs

Short exposure may produce discomfort. Prolonged inhalation of vapor or cold gas, whether respirable or not, can produce serious lung effects.

15.7.2 Toxicity

Most liquefied gases have low toxicity. In high concentration, there may be nausea or dizziness.

15.7.3 Asphyxiation

Adequate ventilation is essential when working with cryogenics. A small amount of cryogenic liquid can rapidly convert to a large volume of gas and create a breathing hazard, and in the case of hydrogen, an explosive mixture. After a recorded double fatality where the victims did nothing to escape or attract attention, safety engineers identified the following physiological stages associated with reduced oxygen:

1. 1st Stage - Oxygen reduced from 21 to 14 percent by volume - The breathing volume increases, the pulse rate is accelerated, and the ability to maintain attention and think clearly is diminished. Muscular coordination is somewhat disturbed.
2. 2nd Stage - Oxygen reduced to range 14 to 10 percent by volume - Consciousness continues, but judgment becomes faulty. Severe injuries may cause no pain. Muscular efforts lead to rapid fatigue. Emotions, particularly ill temper, are easily aroused.
3. 3rd Stage - Oxygen reduced to range 10 to 6 percent by volume - Nausea and vomiting may appear. Victim loses ability to perform any vigorous muscular movements or even to move at all. Up to this stage, or even in it, the person may be unaware that anything is wrong. Then his legs give way, leaving him unable to stand, walk, or even crawl. This is often the first and only warning and it comes too late. The victim may realize that he/she is dying, but he/she does not greatly care. It is all quite painless. Even if resuscitation is possible, permanent damage to the brain may result.
4. 4th Stage - Oxygen reduced below 6 percent - Respiration consists of gasps, separated by periods of increasing duration. Convulsive movements may occur. Breathing then stops but the heart may continue to beat for a few minutes.

As can be seen from the descriptions, any reduction in the normal content of the oxygen in the breathing atmosphere must be considered a hazard. In sudden asphyxia, such as that from inhalation of pure nitrogen, unconsciousness is immediate. The individual falls as if struck on the head and may die in a few minutes. If a person becomes groggy or loses consciousness because of displaced breathing air, get the person to a well-ventilated area immediately. If breathing has stopped, apply CPR. Whenever a person loses consciousness, call a doctor immediately.

Where cryogenics are used, a hazard assessment is required to determine the potential for an oxygen-deficient condition. Controls such as ventilation and/or gas detection systems may be required to safeguard personnel.

15.8 Explosion and Fire

15.8.1 Oxygen

An atmosphere that contains more than the normal 21 percent of oxygen by volume creates a dangerous fire hazard. Combustion is the process of reacting with oxygen, so any increase in the percentage of oxygen available increases the chances of fire. It also increases the intensity of a fire once it has started and can even involve materials normally regarded as being relatively nonflammable. Do not permit open flames in any area where liquid oxygen is stored, handled, or used. Electrical equipment approved for hazardous locations shall be required.

15.8.2 Hydrogen

The rapid expansion of cryogenic hydrogen when released in the ambient atmosphere can quickly create an explosive situation. Hydrogen fires burn with an almost invisible flame and pose a particular need to fight from a safe distance. Do not permit open flames in any areas where liquid hydrogen is stored, handled, or used. Electrical equipment approved for hazardous locations may be required. Leaks in hydrogen systems can lead to electrostatic ignition of the escaping gas. The low temperature of cryogenic materials can condense air. Oxygen, because of its higher boiling temperature, will condense more readily and evaporate more slowly than the other major components of the air. Therefore oxygen enrichment will occur, and in the presence of hydrogen, a powerful and sensitive explosive, can be created.

15.8.3 General

Fighting cryogenic fires requires professional assistance. Dry chemical is the preferred extinguishing agent, but portable extinguishers should be used only with prior training for their use in cryogenic fire situations. CO2 extinguishers can cause static discharges of sufficient magnitude to ignite some hydrogen/air or hydrocarbon/air mixtures.

15.9 Obstruction of Vision by Mist

After cryogenic substances have been released, the formation of mist due to condensation of water vapor in surrounding air may severely reduce visibility. In fact, the cold gas stream may extend considerably beyond the mist, posing an invisible hazard of burns, eye exposure, or, in the case of hydrogen, explosion and fire.

15.10 Use of Water

Use of water around cryogenic systems creates special hazards. Just the moisture condensed from the atmosphere may freeze valves and render them inoperable. Vents intended to release dangerous overpressure can be plugged by formation of ice and cause pressure bursts in confining vessels or pipework, followed by release of contents, which may strongly support combustion or be flammable, asphyxiating, anesthetic or toxic. The preferred method of clearing ice buildup and regaining operability is with a flow of water appropriate to the size of the equipment and the local situation.

15.11 Metal Fracture

Embrittlement of materials at cryogenic temperatures constitutes a special hazard because of inadvertent pressure release if lines fracture.

15.12 Pressure Relief

Because of the great increase in volume of a cryogenic when vaporized, it is mandatory to have pressure relief valves in all lines between valves and between shutoff valves and downstream equipment. Relief valves must be rated to vent at a pressure no more than 10 percent above the design pressure of the line or the downstream equipment involved, whichever is the lesser.

15.13 References

- 29 CFR 1910, Subpart H, Hazardous Materials Part 103, Hydrogen, Part 104, Oxygen; Subpart S, Electrical: Part 307 Hazardous (classified) Locations
- NFPA 50, Standard for Bulk Oxygen Systems at Consumer Sites (1996 Edition)
- NFPA 50B, Standard for Liquefied Hydrogen Systems at Consumer Sites (1994 Edition)
- NFPA 53, Guide on Fire Hazards in Oxygen-Enriched Atmospheres (1994 Edition)

- NFPA 321, Standard on Basic Classification of Flammable and Combustible Liquids (1991 Edition)
- NFPA 496, Standard for Purged Enclosures
- NSS 1740.16, NASA Safety Standard for Hydrogen and Hydrogen Systems,
- NSS 1740.15, NASA Safety Standard for Oxygen and Oxygen Systems

15.14 Appendices

15.14.1 Appendix A: Physical Properties of Low-Temperature Liquefiable Gases

						Boiling Point		Freezing Point	
	Chemical Symbol	Molecular Weight	Color of Gas	Color of Liquid	Odor of Gas	°F	(°C)	°F	(°C)
Argon	A	39	None	None	None	-303	(-186)	-308	(-189)
Ethane	C_2H_6	30	None	None	Slightlysweet	-126	(-88)	-297	(-183)
Ethylene	C_2H_4	28	None	None	Slightlysweet	-155	(-104)	-272	(-169)
Helium	He	4	None	None	None	-447	(-266)		
Hydrogen	H_2	2	None	None	None	-423	(-253)	-434	(-259)
Krypton	Kr	84	None	None	None	-243	(-153)	-251	(-157)
Methane	CH_4	16	None	None	None	-258	(-161)	-296	(-182)
Neon	Ne	20	None	None	None	-411	(-246)	-416	(-249)
Nitrogen	N_2	28	None	None	None	-321	(-196)	-346	(-210)
Oxygen	O_2	32	None	Lt. Blue	None	-297	(-183)	-362	(-219)
Xenon	Xe	131	None	None	None	-162	(-108)	-170	(-112)

15.14.2 Appendix B: Hazards of Low-Temperature Liquefiable Gases

	Argon	Ethane	Ethyl-ene	Helium	Hydrogen	Krypton	Methane	Neon	Nitrogen	Oxygen	Xenon
Cold contact burns	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Risk of frostbite or exposure	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Inhalation produce respiratory discomfort	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exposure to vapor or cold gas can produce frostbite	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Purging required in all confined space	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes (Fire Hazard)	Yes
Toxicity	Nil	Anes-thetic	Anes-thetic	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Explosion hazard with combustible material	No	No	No	No	No	No	No	No	No	Yes	No
Pressure rupture if liquid or cold gas is trapped	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Combustible	Nil	Yes	Yes	Nil	Yes	Nil	Yes	Nil	Nil	Nil	Nil
Promotes ignition	No	Yes	Yes	No	Yes	No	Yes	No	No	Yes	No
Will condense air (explosion hazard)	No	No	No	Yes	Yes	No	No	Yes	Yes	No	No
Flammable limits i oxygen % by volume		3 - 66	3 - 80		4 - 94		5 - 61				
Flammable limits i air % by volume		3 - 12	3 - 32		4 - 75		5 - 15				
Spontaneous ignition temperatu in air at atmospheric pressure °F		959	810		1076		1000				
(°C)		(515)	(432)		(580)		(538)				

15.14.3 Appendix C: Resources

1. Edeskuty, F. J., and Stewart, W. F., *Safety in the Handling of Cryogenic Fluids,* Plenum Press, New York, 1996
2. Davis, M. L., Allgeier, R. K. Jr., Rogers, T. G., and Rysavy, G. *The Development of Cryogenic Storage Systems for Space Flight.* Office of Technology Utilization, NASA, Washington, D.C., 1970
3. Moroni, V. *Thermodynamic Evaluation of a Supercritical Cryogenic Storage System.* Manned Spacecraft Center, Houston, Texas, 1968.
4. Joint Army, Navy, NASA, and Air Force (JANNAF), *Liquid Propellant Handling, Storage, and Transportation,* 1974.

5. Lyndon B. Johnson Space Center (JSC) safety documentation:
    - JSC Requirements Handbook for Safety, Health, and Environmental Protection, JPG 1700.1G (August 1996):
        - Chapter 305, Cryogenic Liquids and Gases: How to Work with Them Safely
        - Chapter 501, Electrical Safety
    - Lockheed Martin Engineering & Sciences Energy Systems Test Area (1995):
        - ESTA-OP-0-47B: Liquid Hydrogen Systems Operator Certification
        - ESTA-OP-0-67: Liquid Oxygen Systems Operator Certification
    - Mission Operations Directorate, Space Flight Training Division; Electrical Power System Training Manual, EPS 2102 (1995)

    Lewis Research Center Safety Manual:
    - Chapter 5, Oxygen Propellant
    - Chapter 6, Hydrogen Propellant
    - Chapter 7, Process Systems and Structural Safety
    - Chapter 25, Combustible-Gas, Toxic-Gas, and Low-Oxygen Detection Systems

    Marshall Space Flight Center Safety Manual MM 1700.4D:
    - Chapter 17, Standard for Use, Handling, and Storage of Compressed Gas
    - Chapter 18, Standards for Hydrogen
    - Chapter 21, Standards for Oxygen

    White Sands Test Facility, Propulsion Department:
    - Cryogenics Handling, PD-003 (1996)
    - LH2 Handling Training, PD-025 (1996)

END OF DOCUMENT