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Glenn Safety Manual – Chapter 5

Oxygen w/Change 3 (6/28/2017)

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Change Record

Rev.	Effective Date	Expiration Date	GRC-25, Change Request #	Description
B	12/19/12	12/19/17	85	Biannual Review/Revision
Change 1	4/11/14	12/19/17	N/A	Administrative changes to add front cover and change history log to comply with NPR 1400.1 and added "The GRC shall follow the requirements of NPR 1800.1C" in Section 4.0 Policy.
Change 2	9/30/15	12/19/17	N/A	Administrative change to remove hyperlinks
Change 3	6/28/2017	12/19/2018	N/A	Administrative change to extend the expiration date to December 19, 2018, to allow more time to address the chapter revisions; changed document number from GLM-1700.1.25 to GLP-QS-8715.1.5.

***Include all information for each revision. Do not remove old revision data. Add new rows to table when space runs out by pressing the tab key in the last row, far right column.*

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> ***NOTE:*** *The current version of this chapter is maintained and approved by the Safety and Health Division (SHeD). The last revision date of this chapter was December 2012. The current version is located on the Glenn Research Center (GRC) intranet within the BMS Library. Approved by Chief of Safety and Health Division.*

1.0 PURPOSE

This chapter serves as a guideline, and reference to more detailed information, for the safe design, fabrication, and use of systems for gaseous and liquid oxygen at the Glenn Research Center (GRC). A summary of operational hazards, design considerations, material options, system siting requirements, and oxygen safety and emergency procedures are provided. First aid procedures for contact with cryogenic material, cleanliness specifications for gaseous and liquid oxygen systems, and procedures for filling gaseous oxygen tube trailers are provided. Important references to other oxygen system design and operational guides are given. In most cases, these guides must be used in conjunction with this manual as they provide significantly more detail.

2.0 APPLICABILITY

This chapter is applicable to all civil servant and contractor employees assigned to GRC who purchase, design, operate, maintain, or certify any fixed or portable oxygen system or container. These guidelines shall govern all aspects of oxygen handling and usage at Lewis Field and Plum Brook Station (PBS).

3.0 BACKGROUND

3.1 Operational Hazards of Oxygen

The major hazards associated with use of liquid or gaseous oxygen are fire and explosion. Oxygen-supported combustion of most engineering materials is a potential hazard. Materials considered fireproof in air will burn violently in a pure or enriched oxygen environment. The hazard is not always apparent as oxygen systems can give normal service for extended periods before circumstances combine to yield an incident or fire. One of oxygen's greatest hazards is its non-evident passive mixing with hydrocarbons. Once such a mixture is ignited, the reaction may proceed violently, even explosively.

The use of cryogenic oxygen can cause additional design and exposure problems, such as trapped cryogenic fluids developing explosive high-pressure rupture potentials, oxygen saturated clothing, cryogenic flesh burns, impact ignitions, and numerous other concerns that are detailed within this chapter.

3.1.1 Fire and Explosion

Oxygen supports vigorous or even explosive burning. Materials that burn only sluggishly or not at all in air burn quickly in oxygen. Almost any material will burn. For example, stainless steel, Teflon (DuPont), and silicones, which are generally regarded as fireproof or fire resistant, can burn easily in oxygen under the right conditions.

Some materials that can react violently with oxygen are oil, grease, asphalt, kerosene, cloth, wood, paint, tar, and dirt. Even many metals burn vigorously in gaseous oxygen. Violent fires in high-pressure oxygen systems have resulted from component failures, entrained metal particles in the flowing gas system, and rapid metal-to-metal contact within components.

Materials will ignite at considerably lower temperatures in oxygen environments than in air, and combustion rates are greater in oxygen than in air. Ignition occurs when a combustible material is heated to ignition temperature. The temperature rise could be from within the oxygen system, without any added energy from outside sources. Fluid friction, chemical reactions, adiabatic compression, or impact on container walls can produce sufficient energy for ignition to occur in oxygen systems.

Leaking or spilled liquid oxygen can form potentially dangerous high concentrations of oxygen gas. In an oxygen-rich environment, clothing may become saturated with oxygen, ignite readily, and burn violently.

3.1.2 Cryogenic and Mixing Hazards

The very low temperature of liquid oxygen aids in condensing foreign matter and freezing out many impurities that may react with oxygen at a later time. Oxygen is easily contaminated because many gases and liquids are soluble in it and some are completely miscible. If an odorless and colorless gas is dissolved in oxygen, problems can result. In fact, inadvertent mixing of oxygen and a flammable gas can cause an explosion, and allowing argon or nitrogen to mix with and enter oxygen-breathing systems can cause death.

Other health hazards are associated with the very low temperature of liquid oxygen. Frostbite results when such liquid or a non-insulated pipe containing it contacts the skin.

Breathing pure oxygen for limited periods of time (an hour or two) will not have any toxic effects; however, the upper respiratory tract may become irritated if the gas is very dry.

When liquid oxygen is trapped in a closed system and refrigeration is not maintained, pressure rupture may occur. Oxygen cannot be kept liquid if its temperature rises above the critical temperature of –181.4 °F (154.6 K).

3.2 Managing the Oxygen Hazard

The oxygen hazard can be managed by minimizing the severity of the environment (i.e., the system's operating parameters and practices) and using materials and designs best able to withstand the environment. Generally, using as many as possible of the following steps minimizes the overall probability of a significant incident (American Society of Testing Materials (ASTM) committee G4.05)

1. Cleaning scrupulously and maintaining cleanliness
2. Adopting certain practices, such as opening valves slowly and using valves with flow capacity to limit downstream pressurization rates
3. Using automated hardware (or isolating or shielding the hardware) to reduce personnel exposure
4. Minimizing flow velocities
5. Using fire-resistant materials to improve the system's ability to withstand its environment

3.3 Properties of Oxygen

Oxygen is an element that at atmospheric temperatures and pressures exists as a colorless, odorless, and tasteless gas. High-purity liquid oxygen is a light blue, transparent liquid. It is an extremely cold cryogenic fluid, which makes handling it potentially hazardous. It boils at –297 °F (90 K) at atmospheric pressure. It boils vigorously at ambient conditions. See Appendix B, Table B.1 for more information on the physical properties of oxygen.

3.3.1 Solubility

Most common solvents are solid at liquid oxygen temperatures. Liquid oxygen is completely miscible with liquid nitrogen and liquid methane. Light hydrocarbons are usually soluble in liquid oxygen and such mixtures are very hazardous.

3.3.2 Reactivity

In either gaseous or liquid form, oxygen is a strong oxidizer that vigorously supports combustion. A material's rate of reaction with oxygen depends on the conditions of its exposure to oxygen and its physical and chemical properties. A particular material may react with oxygen at a rate ranging from very slow to explosive or detonable. The ignition temperature of a material in oxygen systems is not an absolute property. It depends on many factors. To date, no single test has been developed that can be applied to all materials to produce absolute ignition temperature values. However, relative ranking and estimated ignition temperatures for many materials have been established through experimentation. Representative values are found in Chapter 3.4 of "Oxygen Systems Engineering Review" (Schmidt and Forney, 1975).

4.0 POLICY

The authority for the oxygen system safety program at GRC comes from the following:

- NASA Procedural Requirement (NPR) 8715.3: NASA General Safety Program Requirements
- NASA Policy Directive (NPD) 8710.5: NASA Safety Policy for Pressure Vessels & Pressurized Systems
- NASA STD 8719.17: NASA Requirements for Ground Based Pressure Vessels and Pressurized Systems (PV/S)
- Glenn Safety Manual, chapter 1: Safety and Health Management System
- 29 CFR, 1910.104: Oxygen

The primary consideration for resolving oxygen hazards shall be to eliminate them by proper design (see NPR–8715.3, NASA General Safety Program Requirements). Liquid and gaseous oxygen shall be stored, handled, and used so that life and health are not jeopardized and the risk of property damage is minimized. Hazards that cannot be eliminated by design shall be controlled by taking the following corrective actions in this order of precedence:

1. Designing for minimum hazard and allowing for verification of cleanliness to the required level
2. Installing safety devices
3. Installing alarms and warning devices; developing administrative controls, including special procedures and training
4. Providing protective clothing and equipment

Oxygen system design shall be accomplished or reviewed by experienced oxygen system engineers. The references listed in Section 8.0 are highly recommended for use by designers. Adherence to these, however, depends upon the nature and specific conditions of the system under design or operation. Many factors are involved in selecting design criteria and no one standard or guide can be followed in all cases.

An organization using oxygen systems can considerably increase its ability to do so safely by adopting and instituting organizational practices that have been developed and used successfully by the NASA lead developers of ASTM MNL36. An organization using oxygen systems shall establish and maintain necessary policies and procedures to control all phases of an oxygen system from its concept, through design, installation, cleaning, service and decommissioning.

Requests for waivers to NASA Safety and Mission Assurance (SMA) standards related to oxygen use are to be submitted to the Safety and Health Division (SHeD) and to the appropriate GRC authority having jurisdiction (AHJ) for review and final approval. The GRC shall follow the requirements of NPR 1800.1C.

5.0 RESPONSIBILITIES

5.1 Owner/Operators of Oxygen Systems

NASA employees and contractors responsible for the design, operation, or maintenance of oxygen systems at GRC will meet the requirements of the NASA documents located in Section 4.0, Policy. Systems shall be designed, built, and operated utilizing the guidelines of this chapter as well as the given references as applicable or to equivalent levels of safety. Deviations or alternate designs and operation from the references shall be reviewed by experienced staff including the pressure systems office, the area safety committee, and SHeD.

5.2 Supervisors of Operating Personnel and System Designers

Supervisors shall certify that personnel directly involved with the design, installation, and operation of oxygen systems meet minimum training requirements and have knowledge appropriate to the task as recommended in Section 6.1 below. The extent of training depends upon the complexity of the system. For operators and designers of systems containing liquid oxygen or larger volumes of compressed oxygen gas, such as tube trailers, the training requirements of Section 6.1 apply.

5.3 Owner/Operators of Pressurized Oxygen Systems

See the Glenn Safety Manual, Chapter 7, Pressure System Safety, for responsibilities related to pressurized systems. The pressure systems office reviews all oxygen systems for proper design as part of the certification process.

5.4 GRC Safety and Health Division (SHeD) Safety Engineer

The SHeD is responsible for assisting Center personnel with compliance and safety information, hazard analyses, and training resources for safe design and operation of oxygen systems. The SHeD process safety engineer will work with design engineers, system owner/operators, and safety committees to advise on, evaluate, and resolve oxygen system operational, compliance, and safety issues. The SHeD process safety engineer will review oxygen or pressure system waiver requests for proper content including a description of the system and the hazards, overall risk assessment, and acceptability of the proposed mitigation.

5.5 Area Safety Committee Member

The responsibilities of GRC safety committees are defined in Chapter 1 of the Glenn Safety Manual. Area safety committees will ensure that the design and operation of oxygen systems at GRC follow appropriate standards as defined in this chapter and that a sufficient review of the hazards has been completed with associated risk analysis. For process systems and test cells containing pressure systems, the safety committee will permit operation only upon the pressure systems being certified, excluded from certification requirements, or an approved variance in place. This requires that verification of certification, an exclusion, or an approved variance be included in any permit application package containing a pressure vessel or pressure system.

6.0 REQUIREMENTS

6.1 Training (*ASTM MNL36*)

Personnel who handle or use liquid and gaseous oxygen or who design equipment for oxygen systems must become familiar with its physical, chemical, and hazardous properties. Supervisors will certify that employees have sufficient training and knowledge appropriate to the task assigned. Most tasks involving the design or operation of systems involving gaseous or liquid oxygen will require training and certification as described below in Sections 6.1.1 and 6.1.2. Supervisors will determine the suitability of the training. Work involving small quantities, such as single cylinders of gas, may not require the same level of training as that for larger systems.

Training shall familiarize personnel with the nature of the facility's major process systems. Major systems include loading and storage systems; purge gas piping systems; control, sampling, and analyzing systems; alarm and warning signal systems; ventilation systems; and fire and personnel protection systems.

6.1.1 Recommended Training

The following NASA Safety Training Center (NSTC) classes are recommended for operators of oxygen systems at GRC.

Class Number	Class Name
SMA–SAFE–NSTC–0317	Safety in High Pressure Operations
SMA–SAFE–NSTC–0318	Compressed Gas Trailer Safety
SMA–SAFE–NSTC–0319	Compressed Gas Cylinder Safety
SMA–SAFE–NSTC–0056	Flex Hose Safety
SMA–SAFE–NSTC–0052	Fire Hazards in Oxygen Systems
SMA–SAFE–NSTC 053	Oxygen Systems: Operations and Maintenance
SMA–SAFE–NSTC–0313	Cryogenics Safety

6.1.2 Operator Certification

Research personnel, technicians, and system operators shall be certified as “qualified” for handling liquid and gaseous oxygen as applicable to the task and “qualified” in the emergency procedures for handling leaks and spills. Personnel must also be kept informed of any changes in facility operations and safety procedures. Certification requirements for specific potentially hazardous operations are provided in Chapter 2 of the Glenn Safety Manual. Safety permits for operations involving work with oxygen or enriched oxygen require qualified operator certification. This consists of a list of qualified operators and a description of the training completed that must be included in the permit request.

Supervisors will certify (verify) that operators, before working with liquid or gaseous oxygen, have demonstrated the following:

1. Knowledge of the nature and properties of oxygen in both the liquid and gaseous phases
2. Knowledge of approved materials that are compatible with liquid and gaseous oxygen under operating conditions
3. Knowledge of proper equipment and proficiency in its operation
4. Familiarity with manufacturers' manuals detailing equipment operations
5. Proficiency in the use and care of protective equipment and clothing, and safety equipment
6. Proficiency in self-aid, first aid, and proper emergency actions
7. Proficiency in maintaining a clean system and clean equipment in oxygen service
8. Recognition of normal operations and of symptoms that indicate deviations from such operations
9. Conscientiousness in following instructions and checklist requirements

Also, consult the Organizational Development and Training Office—Safety, Health and Environmental Training (SHET) Matrix for operator courses for handling compressed gases and cryogenics.

> 6.1 Verification: The training and knowledge of system designers can be verified by reviewing design records, drawings, and calculations which have the designer and approver name and organization recorded. Supervisors can produce the designer qualifications for review.
>
> Operator training records are available in safety permit documentation or supervisor records for review (GRC580 or other).

6.2 Operational and Protective Measures (*ASTM MNL36*)

6.2.1 Buddy System

All operations involving the handling of oxygen shall be performed under the buddy system as identified in Chapter 22, of the Glenn Safety Manual. The level of the buddy system required will vary with the hazard and complexity of the task, but it shall never be lower than level “d” which is the no-one-alone system. At least two people are required at this level (see Chapter 22 of the Glenn Safety Manual).

6.2.2 Protective Equipment

Protective clothing and equipment shall be included in personnel protective measures. (See Chapter 15 of the Glenn Safety Manual, Personal Protective Equipment, for additional information.)

6.2.2.1 Hand and Foot Protection

Gloves for work near cryogenic systems must be of good insulating quality. They should be designed for quick removal in case liquid oxygen gets inside. Cryogenic gloves do not protect against immersion in liquid oxygen. They are limited to only providing insulative protection from temperature extremes. Because of the danger of a cryogenic splash, shoes should have high tops, and pant legs should be worn outside and over the shoe tops. Leather shoes are recommended.

6.2.2.2 Head, Face, and Body Protection

Personnel handling liquid oxygen shall wear splash protection. A face shield or a hood with a face shield shall be worn. If liquid oxygen is being handled in an open system, an apron of impermeable material should be worn.

6.2.2.3 Impermeable Clothing

Oxygen will saturate clothing, rendering it extremely flammable. Clothing described as flame resistant or flame retardant in air may be flammable in an oxygen-enriched atmosphere. Impermeable clothing with good insulating properties is effective in protecting the wearer from burns due to cryogenic splashes or spills, but even these components can absorb oxygen.

6.2.2.4 Oxygen Vapors on Clothing

Any clothing that has been splashed or soaked with oxygen vapors shall be removed and shall not be used until it is completely free of the gas.

6.2.2.5 Exposure to Oxygen-Rich Atmospheres

Personnel exposed to high-oxygen atmospheres should leave the area and avoid all sources of ignition for at least 20 minutes, until the oxygen in their clothing dissipates. Removal of clothing should be considered.

6.2.2.6 Respiratory Protection

Respiratory protection is not usually required in oxygen operations.

6.2.2.7 Storage of Protective Equipment

Facilities should be available near the oxygen use or storage area for the proper storage, repair, and decontamination of protective clothing and equipment. Safety and protective equipment shall be periodically inspected to ensure it is maintained in reliable condition at all times during use.

6.2.3 Smoking Regulations

1. Smoking and open flames are prohibited within a minimum of 50 feet of an oxygen system.
2. Persons who have been in an oxygen-enriched environment shall not smoke until they have been in a safe area for at least 20 minutes. **Clothing saturated with oxygen vapor is an extreme fire hazard**.

6.3 Emergency Procedures (*ASTM MNL36*)

6.3.1 Emergency Action

The following priority actions shall be followed in case of an accident or emergency:

1. Direct all personnel to evacuate the suspected hazardous area. Activate building evacuation alarms.
2. Call the emergency dispatcher by dialing 9-1-1 at GRC or at PBS. From a cell phone, at GRC call 216–433–8888 and from PBS call 419–621–3222.
3. Isolate or shut off all oxygen supply sources if this can be done safely.
4. Attempt to control the emergency with the installed facility system safety equipment and follow preplanned emergency procedures.

> 6.3 Verification: Verify existence and adequacy of emergency procedures regarding oxygen systems via review of safety permit documentation and or facility procedures and training records. Facility inspections may verify proper egress routes in conjunction with system emergency procedures.

6.3.2 Spills and Leaks

A general fire hazard always exists when a major oxygen leak occurs. Nearby materials, equipment, and buildings may ignite and burn in the oxygen-enriched atmosphere; however, proper system design, material selection, operating procedures, and adequate ventilation will minimize the danger.

Note that an oxygen vapor cloud may persist for a considerable distance downwind of a large liquid oxygen spill because of lack of buoyancy of the cold gas.

6.3.3 Rescue

Only personnel trained in specific rescue techniques shall engage in rescue activities. This will generally be emergency responders such as local fire department personnel. All other personnel shall stay clear of an emergency area.

Rescue personnel must not try to pull a burning victim out of an oxygen-rich atmosphere since the rescuer risks catching fire. Instead, deluge the victim with water and move him/her to fresh air as soon as possible.

Fire blankets must not be used to cover personnel whose clothing is saturated with oxygen. A blanket will prevent oxygen from dissipating from the clothing. Blankets can also become oxygen saturated, thus becoming a fire hazard.

6.3.4 Firefighting/Fire Control

Oxygen-enriched environments make all materials more ignitable, increase burning rates, and, in general, decrease the time available for suppression. Experiments have shown that manual efforts to prevent ignition of adjacent materials once burning has started is very difficult.

Only personnel trained in specific firefighting techniques should be engaged in the firefighting. All other personnel should stay clear of the area.

Procedures for controlling fires involving oxygen vary with the type and circumstances of the fire. The following general recommendations are to be used as a guide.

6.3.4.1 Liquid Oxygen and Fuel

When the fire involves liquid oxygen and liquid fuels, control it as follows:

1. If fuel and liquid oxygen are mixed but not burning, quickly evacuate personnel, isolate the area from sources of ignition, and allow the oxygen to evaporate. Mixtures of fuel and liquid oxygen present an extreme explosion hazard.
2. Should a fuel-liquid oxygen fire occur, shut off fuel and oxygen supplies. Only water sprays or fog should be used to cool the fire. Foams should not be applied. The foam will retard oxygen evaporation and will not extinguish the fire.

6.3.5 Transportation Emergencies

Hazards caused by damage to oxygen transportation systems (road, rail, air, and water) include spills and leaks. Such spills may result in fires and explosions.

The first concern should be to prevent injury or death. In an accident or emergency, efforts should be made to move the oxygen transportation system to an open, safe location provided there is minimum risk of injury to personnel in doing so. All possible ignition sources should be removed and access restricted. If there has been major damage to the vacuum shell or vent system, pressure may build up, causing the liquid oxygen container to rupture explosively. Use water to extinguish secondary fires.

6.3.6 Decontamination of Liquid Oxygen and Fuel Mixtures

Oxygen will eventually evaporate from contaminated surfaces, given time and adequate ventilation.

When liquid oxygen has been contaminated by fuel, isolate the area from sources of ignition and quickly evacuate personnel. Allow the oxygen to evaporate and the residual fuel to reach ambient temperatures. Purge the oxygen system with gaseous nitrogen prior to any other cleanup step.

6.3.7 First Aid

Contact with liquid oxygen or its cold boil-off vapors can produce cryogenic burns (frostbite). Unprotected parts of the body should not be allowed to contact non-insulated pipes or vessels containing cryogenic fluids. The cold metal will cause the flesh to stick and tear.

Treatment of truly frozen tissue requires professional medical supervision since incorrect first aid practices almost always aggravate the injury. For reference, recommended emergency treatments for a cryogenic burn are outlined in Appendix C; they shall be posted in oxygen handling areas.

6.4 Oxygen Storage and Use Locations (*ASTM MNL36, NASA STD 8719.12*)

Suitable protection shall be provided between oxygen storage containers and incompatible materials, storage tanks, plant equipment, buildings, test areas, and property lines so that any accident or malfunction has a minimum effect on facility personnel and public safety. This protection may include separation by distance and by protective structures such as barricades or cell enclosures. The amount of separation required is based on the quantity of propellant present and the propellant use at the location. Planning for protection and safety of personnel and equipment must start at the initial facility design stages.

Oxygen used alone, as in pump, heat transfer, or component tests and bulk storage, can be stored safely without extensive separation distances from neighboring activities or structures as long as fuels are not present. The installation and location of such oxygen storage systems shall conform to the requirements in Sections 6.4.2 of this chapter.

When oxygen is used in conjunction with fuels, such as in combustion tests, rocket tests, or oxygen storage near fuel storage, additional requirements govern the storage and use locations. Quantity-distance requirements in Section 6.4.3 govern these situations, with specific distances required for different fuels, depending on the quantities of fuel and oxygen present.

6.4.1 Quantity Distance

The quantity-distance relations are intended as a guide in the choice of sites and separation distances. The distances given are based on the total quantity of propellants present. These distances may be difficult to achieve, but proper design can sometimes guarantee that only a portion of the total propellants will be involved in an accident. The proper design requires an extensive hazards analysis that would detail all hazards, controls, safeguards, recommendations, risk indices, and applicable code analyses. Separation distances may be waived where small quantities of liquid oxygen are used in well-controlled laboratory experiments. A hazard analysis shall be performed for each facility propellant system or subsystem. Whenever a site does not meet the quantity-distance requirements of Section 6.4.2, the appropriate design, hazards analysis, and specific deviation request are to be submitted to the appropriate area safety committee for evaluation.

6.4.1.1 Quantity-Distance Concept

Quantity distances are based on the concept that the effects of fire, explosion, and detonation can be reduced to tolerable levels if the source of hazard is kept far enough from people and facilities. These distances are based entirely on the estimated damage that could result from an incident, without considering probabilities or frequency of occurrence. Tests and experience are employed to determine how the effects of an accident are related to the quantity of material involved in the accident.

6.4.2 Quantity-Distance Guidelines for Storing Bulk Liquid Oxygen for Nonpropellant Use (Without Fuels)

The required separation distance of nonpropellant bulk oxygen storage systems from a number of different exposures, including inhabited buildings, public traffic routes, property lines, flammable and combustible materials, etc…. is given in 29 CFR 1910.104 and NFPA 55. At GRC these requirements apply to non-propellant applications. These standards contain very similar requirements with some difference in the definition of a bulk system capacity. NFPA 55 has some additional recommendations also. Using these distances assumes that all other requirements of the relevant sections of the standard are followed. Note that fire barriers can affect the required distances for some of the exposure categories. Quantity-Distance Guidelines for Storing Bulk Liquid Oxygen for Propellant Use

6.4.3

When liquid oxygen storage and fuel systems are part of a test stand or test area, there is a possibility of reaction with the oxidizer and fuel outside of the normal test parameters or system. A potential reaction is explosion or detonation of the oxygen-fuel mixture with resulting blast overpressure and fragments. For liquid oxygen in conjunction with a liquid fuel, the quantity distances are based on blast hazards and fragmentation. These quantity-distance determinations are given in NASA STD 8719.12, "Safety Standard for Explosives, Propellants, and Pyrotechnics". NASA STD 8719.12 defines specific hazardous locations associated with propellant / engine testing such launch pads, static test stands, ready storage, etc….. A test area in one of these categories shall have QD determined per NASA STD 8719.12. A method for determining the QD is given for each specific hazardous location category. This requires determination of total propellant weight and possibly explosive equivalent (depending on location category). The quantity distances are those to inhabited buildings and public traffic routes and intraline distances for various quantities of equivalent propellant mixtures. Intraline distance is the minimum distance necessary to limit direct propagation of an explosion by the blast wave from one run or storage complex containing both oxidizers and fuels to another similar complex. Personnel injuries of a serious nature owing to fragments, debris, firebrands, and such are likely.

6.4.4 Quantity-Distance Guidelines for Gaseous Oxygen Storage

Quantity-distances for bulk gaseous oxygen storage facilities are intended to provide facility protection from external fire exposure. The installation and location of bulk gaseous oxygen systems shall conform to the requirements in NFPA 55. As defined by NFPA 55, a bulk oxygen system is an assembly of equipment, such as oxygen storage containers, pressure regulators, safety devices, vaporizers, manifolds, and interconnecting piping, that has a storage capacity of more than 20,000 cubic feet (566 cubic meters) of oxygen, including unconnected reserves at the site. The bulk oxygen system terminates at the point where oxygen at service pressure first enters the supply line. The oxygen containers may be stationary or movable.

Bulk oxygen storage systems shall be located either above ground and outdoors or shall be installed in a building of fire-resistant construction that is adequately vented and is used exclusively for storing oxygen. Fire-resistant building construction is defined in NFPA 220, Standard on Types of Building Construction.

Containers and associated equipment should not be located beneath or be exposed to the failure of electric power lines or piping containing any flammable liquid or gas.

6.4.5 Site Considerations

To provide minimum risks to personnel and equipment, liquid oxygen installations shall be at recommended distances from buildings, fuel storage facilities, and piping. An impermeable, noncombustible barrier shall be provided to deflect any accidental flow of oxygen liquid or vapor from hazardous equipment such as pumps, energized electrical equipment, fuel lines, and so on. In addition, the following guidelines apply:

- Manholes and cable ducts are not safe for oxygen storage and test areas.

- Noncombustible barriers shall be provided to deflect any accidental flow of liquid oxygen away from the site boundaries and control areas.
- The release of spilled oxygen into public drainage systems must be prevented.
- Liquid oxygen tanks shall be located away from oil lines and places where hydrocarbons and fuels can accumulate.
- The location and amount of flammable liquid in nearby storage areas should be reviewed frequently.
- Ground slope modifications, appropriately sized gullies and dikes, and barricades should be used for protection.
- Oxygen storage and use facilities shall be protected from pump failures and other possible sources of shrapnel.
- Liquid oxygen systems shall not be located over or near asphalt roadways.

6.4.5.1 Barricades

Shrapnel-proof barriers may be used to prevent the propagation of an explosion from one tank to another and to protect personnel and critical equipment. The proper height and length of a barricade shall be determined by line-of-sight considerations. Barricades, when required, must block the line of sight between any part of equipment from which fragments can originate and any part of the protected items. Protection of a public roadway shall assume a 12-foot-high vehicle on the road. Barricade design shall comply with DOD 6055.9.

Barricades are needed in oxygen test areas to shield personnel, Dewars, and adjoining areas from blast waves or fragments and may be needed to isolate liquid oxygen storage areas that are close to public property.

6.4.5.2 Dikes, Shields, and Impoundment Areas

To control travel of liquid and vapor due to spills, the facility should include dikes, shields for diverting spills, or impoundment areas. Any loading areas and terrain below transfer piping should be graded toward a sump or impoundment area.

Dikes surrounding liquid storage vessels shall be designed to contain 110 percent of the liquid oxygen in the fully loaded vessel.

6.4.5.3 Structures

The storage facility (including support structures, roadways, drainage, etc.) should be made of fire-resistant materials and should be well ventilated. Normally, because of their special insulation, liquid oxygen storage tanks are not covered. If a storage facility requires protection, any open shed structure of fire-resistant materials may be used.

6.4.5.4 Ventilation

Areas in which liquid oxygen is handled must always be well ventilated to prevent excessive concentration of the gas. The liquid must never be disposed of in confined areas or in places that others may enter. Gaseous oxygen will increase the intensity of any fire.

6.4.5.5 Grounding and Lightning Protection

Buildings, storage systems, and transfer facilities shall be properly grounded against static electricity (resistance to ground checked every 6 months and less than 10 ohms) and should have approved lightning protection.

6.4.5.6 Housekeeping

Surrounding areas shall be kept free of grease, oil, oily waste, and all other organic materials (including vegetation). Smoking, sparks, and open flames are not permitted in storage areas.

6.4 Verification: Siting criteria for oxygen storage or use is defined in the system design documentation and can be reviewed in the safety permit package or facility records. The approved criteria (in compliance with the above requirements) can be audited via a facility inspection of the system and or storage vessel(s).

6.4.5.7 Hazard Warning

The bulk oxygen storage location shall be permanently placarded “OXYGEN – NO SMOKING – NO OPEN FLAMES.”

6.4.6 Electrical Wiring and Equipment

Oxygen storage and test installations are not classified as hazardous locations as defined and covered in Article 500 of NFPA 70, National Electrical Code. Therefore, general purpose or weatherproof types of electrical wiring and equipment are acceptable, depending on whether the installation is indoor or outdoor. Such equipment shall be installed in accordance with the applicable provisions of NFPA 70.

Instrumentation and signal conditioner circuitry installed in oxygen propellant systems should be designed to minimize the overheating and arcing that might result from a sensor system short. Materials should be chosen to minimize the chance of ignition should a short occur. In situations where arcing can occur, testing should verify that the maximum possible spark energy is insufficient to cause ignition of adjacent materials (Bond, et al. 1983).

6.5 Materials (*ASTM MNL36, ASTM G 63, ASTM G 94*)

Safe use of oxygen requires the control of potential ignition energy mechanisms within oxygen systems by judiciously selecting ignition-resistant materials.

6.5.1 Factors Affecting Selection

The basic reason for pursuing oxygen compatibility in systems is to minimize the fire hazard; it is wholly separate from considerations of corrosion, chemical attack, mechanical stability, material physical properties, and the ability to withstand cleaning procedures.

The selection of a material for use with oxygen or oxygen-enriched atmospheres is primarily a matter of understanding the circumstances that cause oxygen to react with the material. Most materials in contact with oxygen will not ignite without a source of ignition energy. When an energy input exceeds the configuration-dependent threshold, ignition and combustion may occur.

To safely use oxygen, appropriate ignition-resistant materials specific to the oxygen environment must be selected. Only those oxygen-compatible materials that have demonstrated combustion resistance well above the maximum expected operating conditions at each local area in a system should be chosen. Currently, no single test has been developed that can be applied to all materials to determine either absolute ignition limits or consistent relative ratings.

Major progress toward enabling oxygen systems to cope with the demands for higher performance, pressures, temperatures, and so forth has been made by designing systems that protect or shield the more susceptible non-metallic material from direct impingement or interface with oxygen (Bond, et al. 1983) and by empirically testing materials in configurations representing their intended uses.

6.5.2 General Guidelines for Materials Selection

The final selection of a material for an oxygen application is an engineering tradeoff involving the chemical compatibility, the ignition and combustion characteristics, the physical properties of the material, the cost, and the consequences of a failure. Proper material choices, based on experimentally obtained databases, can markedly reduce the probability of system ignition. Relative ranking and apparent ignition temperature values for many materials have been established through experimentation.

Materials selected for cryogenic oxygen service shall have the required structural ductility and notch sensitivity characteristics.

The following references are strongly recommended:

- ASTM MNL36: Safe Use of Oxygen System Design, Material Selection, Operations, Storage, and Transportation,
- Design Guide for High Pressure Oxygen Systems (Bond, et al. 1983); and Fire Hazards in Oxygen Systems (ASTM G4.05).
- ASTM G63–92: American Society of Testing and Materials, Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service
- NFPA 53: Recommended Practice on Materials, Equipment, and Systems Used in Oxygen-Enriched Atmospheres.

6.5.3 Metals for Low-Pressure Oxygen Service

6.5.3.1 Gaseous Oxygen

Metals acceptable for low-pressure (nominally less than 1000 psia) gaseous oxygen service include

- Aluminum-nickel
- Aluminum alloys-nickel alloys
- Copper-stainless steel
- Copper alloys

See Table B.2, Some Recommended Materials for Oxygen Service, for a partial list of these materials and their applications.

6.5.3.2 Liquid Oxygen

Metals recommended for service with liquid oxygen are

- Nickel and nickel alloys
  - Hastelloy B-nickel
  - Inconel-X-Rene 41
  - K-Monel
- Stainless steel types
  - 304–310
  - 304L–316
  - 304ELC–321
- Copper and copper alloys
  - Copper–Cupro-nickel
  - Naval brass
  - Admiralty brass

NOTE: *Refer to Chapter 3, Materials Section of ASTM MNL36: Safe Use of Oxygen System Design, Material Selection, Operations, Storage, and Transportation, January 2000, for more detailed materials information.*

6.5.4 Prohibited Metals

Certain metals are prohibited from being used in oxygen systems (see Restricted Alloys, Chapter 3 of ASTM MNL36).

6.5.4.1 Cadmium

The toxicity and vapor pressure of cadmium restrict its use.

6.5.4.2 Titanium

Titanium metal shall not be used with liquid oxygen at any pressure or with gaseous oxygen or air at oxygen partial pressures above 30 psia. Titanium and its alloys are impact sensitive in oxygen.

6.5.4.3 Magnesium

Magnesium metal shall not be used in oxygen systems. In addition, its alloys shall not be used except in areas with minimal exposure to corrosive environments. Reactivity with halogenated compounds constrains its use with lubricants containing chlorine and fluorine.

6.5.4.4 Mercury

Mercury shall not be used in oxygen systems in any form because it is toxic; in addition, it and its compounds can cause accelerated stress cracking of aluminum and titanium alloys.

6.5.4.5 Beryllium

Beryllium and its oxides and salts are highly toxic and, therefore, they shall not be used in oxygen systems or near oxygen systems where they could be consumed in a fire.

6.5.5 Nonmetallic Materials

The primary concerns about using nonmetals in oxygen systems are their potential reactivity with the oxidant and limitations at cryogenic temperatures. Their ignition temperatures are generally lower than those for metals, and their low thermal conductivity and heat capacity make them much easier to ignite. The selection of these materials for use in oxygen is based on experience and testing of impact, ignition, and flammability characteristics. For more information, consult ASRDI Oxygen Technology Survey, Volume 9 (Schmidt and Forney, 1975) and ASTM MNL36, Chapter 3, Nonmetallic Materials.

Nonmetals that have been used successfully are

- Tetrafluoroethylene polymer (TFE, Halon TFE, Teflon®, or equivalent)
- Unplasticized chlorotrifluoroethylene polymer (Kel F®, Halon CTF, or equivalent)
- Fluoro-silicone rubbers and fluorocarbons (Viton®), batch-tested for acceptability
- Lubricants such as Krytox® and Triolube 16® (Aerospace Lubricants)

Table B. contains a partial list of nonmetals and their applications.

Nonmetallic material selection may be based on data presented in JSC Specification SE R 0006B. Table 2 in Design Guide for High Pressure Oxygen Systems (Bond, et al. 1983) lists ignition variability of nonmetallic materials currently used in oxygen systems and of nonmetallic materials not requiring batch-testing control, along with some use restrictions.

6.5.6 Materials for High-Pressure Oxygen Service

The materials listed in Table B.2 of this chapter (under the high-pressure heading) have demonstrated superior resistance to ignition and fire propagation in high-pressure (nominally greater than 1000 psi) oxygen systems.

6.5.7 Selecting Material by Configuration Testing

This information taken from Bond et al. (1983)

If it is not possible to find, even with batch/lot testing, materials that meet the functional requirements of a design, it may be possible to provide sufficient protection from ignition so that use of a susceptible material may be permitted. If this design approach is used, the adequacy of the design must be demonstrated through configuration testing at conditions more severe than the worst-case environment for the component in question. But configuration tests are considered valid only if they are conducted on hardware identical to the hardware proposed for use.

The configuration tests should use oxygen pressures at least 10 percent above the worst-case condition. Expected temperature limits should be exceeded by at least 50 °F. If the material is to be subjected to rapidly changing

> 6.5 Verification: Material selection criteria for oxygen system components is defined in the system design documentation and can be reviewed in the safety permit package or facility records. The approved criteria (in compliance with the above requirements) can be audited via a system inspection and or review of final component data sheets, material certification, drawings, etc…...

pressures, the pressure rise rate used in the configuration tests should be at least twice that which the component is expected to experience in operation.

If cycling or multiple reuse of the component is a design requirement, the configuration testing should exceed by a factor of 4 the expected number of cycles or reuses. Failure of the configuration test article before completion of the required number of cycles would limit the use life of the component to one-fourth the number of cycles actually completed before failure.

6.5.8 Materials Tests

If a designer chooses a material that has not been previously approved or evaluated for oxygen service, rationale, procedures, and data, as presented in the following guides, shall be provided to the area safety committee, pressure systems office, and SHeD for approval:

- ASTM G 63 87: Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service
- ASTM G 94 90: Standard Guide for Evaluating Metals for Oxygen Service

6.6 System Design (*ASTM MNL36, ASTM G88–90*)

Safe use of oxygen requires the control of potential ignition energy mechanisms within oxygen systems by judiciously selecting system designs. The generally accepted steps in the design process are provided in

- Chapter 5 of ASTM MNL36
- ASTM G88–90, 1991: Standard Guide for Designing Systems for Oxygen
- Design Guide for High Pressure Oxygen Systems (Bond, et al. 1983)

6.6.1 General System Considerations

The following design principles shall be adopted to achieve maximum oxygen safety at GRC.

6.6.1.1 Inherent Safety

Oxygen systems shall be designed selecting materials that are ignition and combustion resistant at the maximum expected operating conditions. Safe oxygen systems must include designs for preventing leaks, eliminating ignition sources, establishing and maintaining a clean system, avoiding cavitation, and preventing resonant vibration.

6.6.1.2 Two Lines of Defense

In addition to the inherent safety features, at least two failure-resistant, independent barriers shall be considered to prevent a given failure from leading to a serious mishap. Thus, at least two undesirable, independent events would have to occur simultaneously under either normal or emergency conditions before there would be a potential danger to personnel or major damage to equipment and property.

6.6.1.3 Fail-Safe Design

The equipment, power, and other system services shall be designed and verified for safe performance in the normal and maximum designed operational regimes. Any failures shall cause the system to revert to conditions that are safest for personnel and that will cause the least property damage. Redundant components shall be incorporated into the design to prevent system failures which can lead to serious consequences.

6.6.1.4 Automatic Safety Devices

System safety valves, flow regulators, and equipment safety features shall be installed to automatically control hazards.

6.6.1.5 Alarms and Warning Systems

Warning systems to monitor those parameters of the storage, handling, and use of oxygen that may endanger personnel and cause property damage shall be incorporated into oxygen system design. Warning systems shall consist of sensors to detect abnormal conditions, to measure malfunctions, and to indicate incipient failures. Data transmission systems for caution and warning systems shall have sufficient redundancy to prevent any single-point failure from disabling an entire system.

6.6.1.6 Formal Procedures

All oxygen operations shall be conducted by knowledgeable, trained, and certified personnel following formal procedures. Personnel involved in design and operations will carefully adhere to the safety standards of this chapter and must comply with regulatory codes. System cleaning procedures shall be adopted from proven methods successfully used in industry or at GRC as defined in Section 6.7.

6.6.1.7 Personnel Training

Personnel assigned to handle/use liquid and gaseous oxygen or to design equipment for oxygen systems must become thoroughly familiar with the physical, chemical, and hazardous properties of oxygen (Section 6.1 of this chapter).

6.6.1.8 Operator Certification

Operators shall be certified to handle liquid and gaseous oxygen under normal and emergency conditions according to Section 6.1.2 of this chapter.

6.6.1.9 Safety Review

At a minimum, all oxygen design, handling, and test operation activities shall be subject to an independent, third-party safety committee review and subject to a permit issued by the responsible area safety committee. In addition, any modification to a facility oxygen system or research hardware shall be brought to the attention of the appropriate safety committee for review prior to operation.

6.6.2 Velocity and Thermal Considerations

The use of high-pressure oxygen requires certain design considerations that need special attention at the system level. The architecture, flow dynamics, and thermal design of the system are important.

6.6.2.1 System Flow Velocity

From Bond et al. (1983); Schmidt and Forney (1975); and Williams, Benz, and McIlroy (1988).

The primary source of concern under high-velocity oxygen flow conditions is the entrainment of particulates and their subsequent impingement on a surface, such as at a pipe bend. The result can be propellant system ignition. The following flow dynamics design practices are recommended to avoid oxygen system fires:

1. If practical, avoid velocities that are nominally above 100 feet/second in gaseous oxygen and avoid cavitation in liquid oxygen. Where this is impractical, use the alternate materials recommended in the references called out in Section 6.5 or those listed under the "High Pressure" column of Table B.2 of this chapter.

   NOTE: *During testing at NASA White Sands Test Facility (WSTF) in 1988, the oxygen velocities required for ignition of carbon steel, 316 stainless steel, and 304 stainless steel owing to the impact of a standard particle mixture were investigated at various oxygen pressures. Ignition of the particle mixture and the three alloys occurred at oxygen velocities greater than 146 feet/second and at pressures between 2900 and 3480 psi. The WSTF data suggest that specimen ignition appears independent of pressure up to about 4000 psi. Compared with these tests and other recent data, the CGA (CGA G 4.4) oxygen velocity limits for safe operations may be excessively conservative at high pressures and too liberal at low pressures. During 1991 communications with WSTF, they consider flow velocities of 100 feet/second in gaseous oxygen systems to be low-velocity flow. This value has been selected as the current guideline design value for this chapter. (See Williams, Benz, and McIlroy, 1988 for details.)*

2. If possible, avoid the use of nonmetals at locations within a system where sonic flow or cavitation can occur.

3. Maintain fluid system cleanliness and limit entrained particulates as specified in Section 6.7.

6.6.2.2 System Thermal Design

System thermal design considerations shall include thermal conditioning at startup and avoiding the lockup of cryogenic oxygen in a system segment. It is necessary to bring components to thermal equilibrium before starting up cryogenic oxygen turbo-pump systems and to avoid hazardous component thermal transients which may affect fits and clearances, cause rotor dynamic instabilities, or lead to high-speed rubbing friction. Any of these problems may result in ignition. Provision shall be made to provide thermal conditioning of the cryogenic system and components by gradually bleeding through cryogenic gas and then liquid.

Cryogenic oxygen hydraulically locked up between two valves or flow control components can absorb heat and, through the increase of pressure, cause structural failure. The system and components shall be designed to provide appropriate pressure relief.

6.6 Verification: System design documentation may be reviewed during safety permit reviews or any other time to verify the above requirements were incorporated or considered in the process.

6.7 System Cleanliness (*ASTM MNL36, ASTM G93–88, CGA G–4.1*)

Safe use of oxygen requires the control of potential ignition energy mechanisms within oxygen systems by maintaining scrupulously clean systems. Cleanliness (contamination control) is critical in oxygen components and systems. Contamination can cause ignition of components or systems by a variety of mechanisms, such as particle impact, mechanical or pneumatic impact, or spontaneous ignition. In an oxygen environment, contaminants increase the ignitability of both metallic and nonmetallic materials.

6.7.1 General Policy

Before being placed in service, liquid and gaseous oxygen systems and their system components shall be completely cleaned to meet GRC end-result cleanliness quality specifications (Section 6.7.4).

Furthermore, since oxygen components and systems shall be periodically reinspected to ensure that safety and component integrity are maintained during the life of the system, there are more opportunities for contamination. If the oxygen system contains components with a history of in-service failures, appropriate traps or other easily analyzed components shall be removed, inspected, and periodically replaced (Section 6.7.5).

6.7.2 Oxygen Cleanliness Supplements

The following publications contain proven, practical guidelines that were developed to safely and successfully control contamination in oxygen propellant systems.

- ASTM G93–88: Standard Practice for Cleaning Methods for Materials and Equipment Used in Oxygen-Enriched Environments
- CGA Pamphlet G–4.1: Cleaning Equipment for Oxygen Service
- NASA Reference Publication 1113: Design Guide for High Pressure Oxygen Systems, Chapters 6 to 8 (Bond, et al. 1983)
- ASRDI Oxygen Technology Survey, Volume 2: Cleaning Requirements, Procedures, and Verification Techniques (Bankaitis and Schueller, 1972)
- MSFC Spec 164: Cleanliness of Components for Use in Oxygen, Fuel, and Pneumatic Systems (contains acceptable methods of cleaning pipe, tubing, and flex hose)
- KSC–C–123: Specifications for Surface Cleanliness of Fluid Systems

6.7.3 Cleaning Procedures

Cleaning methods and subsequent inspections must produce the degree of cleanliness required for the safe operation of oxygen service equipment and the necessary propellant purity required for experimental test operations.

Cleaning a component or system for oxygen service involves the removal of combustible contaminants, including the surface residue from manufacturing; hot work, and assembly operations, as well as the removal of all cleaning agents. These cleaning agents and contaminants include solvents, acids, alkalis, water, moisture, corrosion products, non-compatible thread lubricants, filings, dirt, scale, slag, weld splatter, organic material (such as oil, grease, crayon, and paint), lint, and other foreign materials.

Injurious contaminants can be removed by cleaning all parts and maintaining this condition during construction; by completely cleaning the system after construction; or by a combination of the two.

The prevention of recontamination before final assembly, installation, and use is essential to safe oxygen system operation.

The organization performing the cleaning service shall have the responsibility of developing detailed cleaning procedures. The GRC oxygen systems cleanliness acceptability shall be based only on the quality specifications of the cleaning end result and not on the cleaning procedures used. The organization performing the cleaning shall be completely responsible for meeting the cleanliness specifications of Section 6.7.4, regardless of the procedures used.

The GRC organization responsible for operating the oxygen system or equipment must be assured that the procedures are compatible with the units being cleaned and that the procedures will accomplish the appropriate level of cleanliness.

The GRC system owner/user has the option of exercising approval authority of the cleaning procedures to be used on his/her systems.

6.7.3.1 Cleaning Procedure Safety

The organization performing the cleaning services shall have responsibility for all safety aspects of oxygen cleaning procedures. Guidance for safe procedures can be found in ASTM G 93–88, Section 8, Cleaning Methods.

6.7.3.2 Special Considerations

Complete systems may require disassembly for suitable cleaning. Components that could be damaged during cleaning should be removed and cleaned separately. Cleaning or disassembly operations that might affect tolerances or impair calibration of precision components should be performed only under the supervision of personnel qualified in the handling, calibration, and assembly of the components.

The cleaning procedures established for each system or component shall be compatible with the design configurations. Prior to use, establish the compatibility of cleaning agents with all construction materials, making sure that time or temperature constraints are not exceeded.

6.7.4 Verification of Oxygen System Cleanliness

A key element of the GRC contaminant control safety plan is the final inspection and verification of system cleanliness by using an approved GRC acceptance specification. Experience has shown that approximately one-half of all parts cleaned fail on the initial sampling to meet either the particulate or the nonvolatile residue (NVR) specification. Should this occur, recleaning is required until all parts pass both specifications (see Bond, et al. 1983).

6.7.4.1 Inspection Procedures

Procedures detailed in ASTM G 93–88, Section 10, Inspection, shall be followed to verify cleanliness of components and systems for GRC oxygen service.

6.7.4.2 GRC Cleanliness Acceptance Criteria

Acceptance criteria for all systems and components are based on KSC–C–123H, Surface Cleanliness of Fluid Systems. The acceptance level shall be 300–A, which is suitable for ground-based gaseous and liquid oxygen propellant systems at GRC (see Table D.1, Appendix D). This acceptance level represents a particle limit and a hydrocarbon limit identical to those that NASA Kennedy Space Center uses on ground equipment in oxygen service.

NASA has no standardized procedures for cleaning components or systems. Cleaning organizations may employ varying methods to meet the acceptance criteria of KSC–C–123H and the GRC Oxygen System Cleanliness specification.

Information on the use of approved substitutes for ozone depleting chemicals can be found at http://smad-ext.grc.nasa.gov/shed/pub/epm/epm19-OZONE(26).pdf. The most recently approved and successfully used solvent has been HFE 7100 for in-place cleaning of oxygen systems at GRC.

6.7.5 Recommendations for Reinspection

Oxygen components and systems shall be reinspected periodically to ensure that safety and component integrity are maintained during the life of the system. Determination of system and component reinspection intervals has proven to be a complex task. Detailed knowledge of construction materials, pressure levels, the use environment, and the service the system is performing must be applied. A record of reinspections must be kept on file and labels placed on the inspected components. In establishing the reinspection intervals, the following items should be considered:

- Routine disassembly and reassembly of piping systems invariably increases the level of system contamination because particulates are generated.

- Sampling of an assembled system for gas-borne contaminants yields only limited data on the internal cleanliness. This method of system sampling cannot be directly correlated with the cleanliness of internal system surfaces.
- The reinspection plan must address the design service life of components.
- Additional insight regarding system contamination levels can be gained through systematic inspection of components (e.g., transducers, flex hoses, relief valves, filters) removed for calibration, proof testing, or periodic maintenance. NASA STD 8719.17 provides in-service inspection requirements for oxygen systems components.
- Cleanliness levels in components and systems that have been in service shall be reverified to make sure the requirements of the GRC Oxygen System Cleanliness specification under Section 6.7.4 of this chapter are met.
- Reassembly procedures shall adhere to guidelines for original assembly, including assembly checkout.

6.7.5.1 Assembly of Propellant Systems

After system and component disassembly and cleaning, reassembly of components and systems must be stringently controlled to ensure that the achieved cleanliness levels are not compromised.

All components requiring reassembly (e.g., valves, regulators, and filters) should be reassembled in a filtered-air environment such as a clean room or flow bench. Personnel should be properly attired in clean-room garments and gloves. All tools that contact component internal parts must be cleaned to the specified levels of the parts.

6.7.5.2 Final System Checkout

After the system has been reassembled, a final pressure integrity and leak test should be performed with an appropriately filtered inert gas that has been analyzed for contaminants. Hydrostatic tests: **It is not recommended that hydrostatic tests be performed on cleaned systems since this is likely to contaminate them**. Conduct these tests on the components before cleaning and final assembly. Refer to Chapter 7, Pressure Systems Safety for pneumatic and hydrostatic pressure testing guidelines.

6.7.5.3 Cryogenic Cold-Shocking

Cold-shocking a newly assembled liquid oxygen system by loading it with clean liquid nitrogen following final assembly is highly recommended. After the cryogenic cold-shocking, the system should be emptied of liquid nitrogen and warmed to ambient temperature. Bolts and threaded connections must then be re-torqued to prescribed values, and gas leak-checking procedures should follow.

The entire system should be inspected for evidence of cracking, distortion, or any other anomaly, with special attention directed to welds. Then system cleanliness must be checked and verified.

6.7.5.4 Final Operational Tests

Final operational tests should be run with oxygen (liquid or gas, as required by the system) at rated pressure. If it is possible to substitute nitrogen for this test, this should be done for greater safety in the operational test. Only verified clean dry nitrogen shall be used for these tests. It is prudent to recheck the system filters for cleanliness after the test is completed.

It is a good practice to perform the first oxygen pressurization of a system by remote control, since assembly-generated contaminants can cause ignition.

> 6.7 Verification: Cleaning records, re-inspection intervals, etc… are to be maintained by system owners / users and may be audited prior to or during testing as well as reviewed during the safety permit review process.

6.8 Operating Procedures and Policies for Oxygen Systems (*ASTM MNL36*)

Safe use of oxygen requires the control of potential ignition energy mechanisms within oxygen systems by using appropriate operational procedures.

6.8.1 Formal Procedures

All oxygen operations shall be conducted by knowledgeable and trained personnel using formal written procedures. Personnel involved in design and operations shall carefully adhere to the safety standards of this chapter and must comply with regulatory codes.

Standard operating procedures (SOPs) with checklists shall be developed for common operations. The SOPs shall be prepared by persons familiar with the work being done and shall be reviewed and implemented by line management. SOPs for all hazardous operations shall be approved by the area safety committee.

The procedures shall be reviewed by a responsible safety committee (at least annually) for observance and improvement. Special procedures shall be developed to counter hazardous conditions when the system design and the use of safety equipment do not reduce the magnitude of a potential hazard to acceptable levels. The effectiveness of these procedures shall be verified through demonstration tests using sound engineering principles and judgment.

The buddy system, as specified in Section 6.2.1, shall be followed for oxygen use operations.

6.8.2 Test Cell Entry

Entry into an operating test cell must be considered dangerous. Authorized personnel may gain entry only after conditions within the cell have been determined to be safe.

Test cells and buildings containing combustible or explosive mixtures shall not be entered under any condition. Personnel should be warned of combustible or explosive mixtures and high or low oxygen concentrations by detectors, sensors, and continuous sampling devices that operate both audible and visible alarms.

6.8.3 Transfer and Flow Guidelines

These general guidelines apply to both gaseous and liquid oxygen operations.

1. Storage, transfer, and test areas should be kept neat and free from combustibles and should be inspected frequently. An adequate water supply should be available for firefighting.
2. The manner in which transfer equipment is operated will be determined by local designs and construction, the type of equipment selected, and the procedures prescribed by either the cognizant authority or the equipment manufacturer.
3. Transfer and flow operations shall include procedures to assure that an appropriate level of oxygen system cleanliness has been reached before oxygen flow is begun.
4. After extended use and after periods of extended shutdown, inspections must be made for possible oxygen system contamination and for evidence of unsafe conditions in the equipment.
5. Great care must be exercised when reusing oxygen that has flowed through a propellant system. Flowing oxygen back to the supply tank may contaminate the supply; dumping or venting once-used oxygen is a preferred procedure.

6.8.4 Oxygen System Maintenance or Repair

Provisions shall be made to keep an oxygen system clean when it is opened for maintenance or repair. The following steps must be taken:

1. Isolate, insofar as possible, the portion of the system to be entered.

2. Verify that the system is drained and depressurized. Purge the oxygen system with an inert gas before opening it.
3. Confirm that the entire system is at ambient temperature to keep contaminated air from being sucked into the system. This is particularly important if a part of the system is nitrogen jacketed. “Breathing” may also be caused by barometric pressure variations or temperature changes. A slight positive pressure or purge may be necessary to keep the system from breathing.
4. Cap or seal openings into the part prior to reinstalling it in the system.
5. Purge and re-clean repaired parts of the system prior to reinstallation.
6. Make provisions for periodic cleaning of possible contaminant traps in a system, but every effort should be made to avoid such traps in the design.
7. When working on equipment where oxygen enrichment is a possibility, isolate the equipment by inserting a blank. A shutoff valve is not considered a positive means of isolation from a working oxygen system.

6.8.5 Operational Procedures for Gaseous Oxygen Tube Trailers and Cylinders

Quick-acting valves must not be used to start or stop gaseous oxygen systems. Most failures in gaseous oxygen systems are caused by sudden flow changes.

6.8.5.1 Specific Requirements for Gaseous Oxygen Tube Trailers

1. All GRC-owned gaseous oxygen tube trailers shall be fitted with remotely operated transfer shutoff valves of a Glenn standardized design and configuration. Only inert gas or air shall be used to operate these remote shutoff valves. Oxygen gas from the trailer sample panel shall NEVER be used to operate valves.
2. Trailer-to-facility transfer lines may be made of corrugated stainless steel or Teflon hose, with the proper pressure rating, inside an external braid of stainless steel. In such cases, proper restraining cables and anchoring are required. Gaseous oxygen flow velocities in the transfer line should be kept below 100 feet/second unless higher velocities can be safely tolerated.
3. Appendix C contains specific operational procedures to connect leak-check, purge, start up, and shut down the Glenn gaseous oxygen tube trailer systems.

6.8.5.2 Operational Procedures for Portable Gaseous Oxygen Cylinders

Specific operational procedures for the safe use of gaseous oxygen cylinders are found in the Compressed Gas Association Pamphlet CGA G 4.

6.8.6 Recommended Operational Procedures for Liquid Oxygen Systems

Specific operational check sheets should be formulated by the design and operations team and encompass the following elements as applicable.

6.8.6.1 Leak-Check Systems

Before operating a liquid oxygen system for the first time, cold-shock the entire system with clean liquid nitrogen and then check for leaks. Before loading, purge the system of air and water vapor. Recheck for cleanliness to be sure that cold shocking and leak checking did not contaminate the system.

6.8.6.2 Loading

Fill the system with liquid oxygen gradually to limit “geysering,” severe local temperature gradients, and surges in the system.

6.8.6.3 Operations

Do not proceed with testing until the system has reached thermal equilibrium. This precaution is particularly pertinent to turbo-machinery components in the system.

6.8.6.4 Shutdown

Purge the oxygen residue from all components of the system.

6.8.6.5 Unloading and Transfer Leaks

Make sure transfer hoses have been disconnected before moving the loading vehicle. Leaks are usually caused by deformed seals or gaskets, valve misalignment, or failures of flanges and equipment. A liquid oxygen leak may cause further failures of construction materials.

6.8.6.6 System Leak Repair

Do not repair any leak until all pressure in the system has been bled. All tools and fittings should be cleaned appropriately before use. If welding or brazing is required, the system must be made inert, repaired, and recleaned.

6.8.6.7 Condensation of Contaminants During Loading

Improper loading procedures for cryogenic oxygen can result in condensation of water or any other condensable vapor inside the system. In large systems, even contaminant levels measured in parts per million can produce a sizable frozen mass that could impede flow or system function.

6.8.6.8 Before Loading a Cryogenic System

Purge or evacuate from the system all air, water, and condensable vapors. Experimentation may be required to define the degree of purge or the number of evacuation cycles required.

6.8.6.9 Sampling Techniques

When required, collect samples of oxygen in a sealed container of appropriate design. Follow cleanliness and purging procedures to avoid contamination of the sample.

6.8.7 Transportation of Oxygen

Oxygen, compressed oxygen, and refrigerated liquid oxygen are subject to the U.S. Department of Transportation regulations for hazardous materials.

For complete information and specifications, refer to Title 49, CFR, Parts 100 to 177, Hazardous Materials Regulations.

6.8.8 Disposal of Oxygen

As classified in Title 40, CFR, Parts 260 to 265, Hazardous Waste Management, oxygen is not considered a hazardous waste. Uncontaminated liquid oxygen is best disposed of by allowing it to vaporize from a normal heat leak into the container and letting the vapor escape through the vent. Liquid oxygen may also be piped into an area free from combustible material and allowed to vaporize.

6.9 Specifications

Liquid oxygen, used as an oxidizer in propellant systems, shall conform to MIL–P–25508E, Military Specification, 1995, Propellant, Oxygen. Type II propellant-grade liquid oxygen contains a minimum of 99.5 percent oxygen; the major impurity is argon. Gaseous oxygen used to purge and pressurize propellant systems shall conform to MIL–P–25508E, Type I or Fed. Spec. BB O–925A. (Properties for *breathing oxygen* are specified in MIL–O–27210F Military Specification, 1997, Oxygen, Aviators Breathing, Liquid and Gas.)

7.0 RECORDS

Certification of System Cleanliness (issued by the organization performing the cleaning or verification)

7.1 Pressure Systems Office (PSO) Certification Documents (all maintained by the PSO)

- Nondestructive examination (NDE) reports
- Risk Assessment Report
- System Certification Report
- Pressure System Database

7.2 NASA C Forms (all maintained by the PSO except the GRC83 and GRC83A)

Form Number	Form Name
GRC83	Safety Variance Request (maintained by SHeD)
GRC83A	Safety Variance Change Request (maintained by SHeD)
GRC802	Pneumatic Test Request
GRC804	Pneumatic Test Permit
GRC4026	Pressure Vessel Pneumatic Test Checklist
GRC4010	Pressure Vessel Pneumatic Test Report
GRC4020	Piping System Pneumatic Test Checklist
GRC4014	Piping System Pneumatic Test Report
GRC4022	Pressure Vessel Hydrostatic Test Checklist
GRC4016	Pressure Vessel Hydrostatic Test Report
GRC4018	Piping System Hydrostatic Test Checklist
GRC4012	Piping System Hydrostatic Test Report
GRC4027	Standard Exclusion Request
GRC4025	Weld Request Form

8.0 REFERENCES

This chapter is based on the best test information available. Much of the material was compiled directly from Bond et al. (1983); Bankaitis and Schueller (1972); Schmidt and Forney (1975); NSS/FP 1740.12; ASTM G93–88; Other sources include CGA Pamphlets G4.1 and S 1.2; NFPA 53 and 55; and Volumes 1 and 3 of CPIA 394.

References mentioned in this chapter can be found in the following locations:

ASTM, CGA, DOD, MIL, and NFPA documents can be obtained by accessing the Agency wide Full Text Standards System (password and ID required).

NPD and NSS documents can be obtained by accessing the NASA Headquarters Directives and Standards page.

Other references may be available in the GRC Library or may be obtained by contacting the Glenn Operational Safety Branch.

Document Number **Document Name**

	Aerospace Structural Metals Handbook: 1989 Publication with 1988 Supplement XXI Incorporated. Metals and Ceramics Information Center, Columbus, OH, 1989.
AFM 161 30	Air Force Manual. 1984: Chemical Rocket/Propellant Hazard
ASTM G4.05	American Society for Testing and Materials. 1990: Fire Hazards in Oxygen Systems. ASTM Standards Technology Training Course book, First ed.
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APPENDIX A.—DEFINITIONS AND ACRONYMS

Adiabatic compression.—Compression of a gas in an adiabatic system. Since energy cannot be transferred to or from the surroundings in an adiabatic system, the compressional energy increases the energy (temperature) of the compressed gas.

American Society of Testing Materials (ASTM)

Authority Having Jurisdiction (AHJ)

Autogenous ignition.—The phenomenon in which a mixture of gases or vapors ignites spontaneously with no external ignition source. It is frequently called autoignition or spontaneous ignition.

Autoignition temperature.—The lowest temperature at which a fuel in contact with air or an oxidizer will self-heat to ignition without an external ignition source. The autoignition temperature for a monopropellant is the temperature at which it will self-heat to ignition in the absence of an oxidizer.

Blast wave.—A shock wave in air caused by the detonation of explosive material

Blast yield.—Energy released in an explosion. The amount of energy is inferred from measurements of the characteristics of blast waves generated by the explosion.

Burn velocity.—The propagation velocity of a flame through a flammable mixture. Burning velocities are absolute velocities measured relative to the velocity of the unburned gas; flame velocities are measured in laboratory coordinates and are not absolute.

Chemical Propulsion Information Agency (CPIA)

Combustion wave.—A zone of burning, propagating through a combustible medium, that is capable of initiating chemical reaction in the adjacent unburned combustible layers

Code of Federal Regulations (CFR)

Compressed Gas Association (CGA)

Critical diameter.—The minimum diameter required for a tube to produce a stable spherical detonation into an unconfined environment. This term is sometimes used by other authors to describe the minimum tube diameter for propagation of a flame or of a detonation confined in the tube.

Deflagration.—A rapid chemical reaction in which the output of heat is enough to enable the reaction to proceed and accelerate without input of heat from another source. Deflagration is a surface phenomenon in which the reaction products flow away from the unreacted material along the surface at subsonic velocity. The effect of a true deflagration under confinement is an explosion. Confinement of the reaction increases pressure, rate of reaction, and temperature and may cause transition into a detonation.

Detonation.—A violent chemical reaction of a chemical compound or mechanical mixture in which heat and pressure are emitted. A detonation is a reaction that proceeds through the reacted material toward the unreacted material at supersonic velocity. As a result of the chemical reaction, extremely high pressure is exerted on the surrounding medium, forming a propagating shock wave that originally is of supersonic velocity.

Detonation cells.—The cellular pattern left on a soot-coated plate by a detonation wave. The dimensions of a single cell (length and width) can be used to predict detonation limits and critical diameters.

Detonation limits.—The maximum and minimum concentrations of vapor, mist, or dust in air or oxygen at which stable detonations occur. The limits are controlled by the size and geometry of the environment as well as by the concentration of the fuel. Detonation limit is sometimes used as a synonym for explosive limit.

Detonation wave.—A shock wave that is sustained by the energy of a chemical reaction initiated by the temperature and pressure in the wave. Detonation waves propagate at supersonic velocities relative to the unreacted fluid.

Diffusion coefficient.—The mass of material diffusing across a unit area in unit time at a unit concentration gradient

Electrical arc/spark test.—Method of determining the susceptibility of metals to ignition in oxygen by using an electrical arc or spark. Arc energy input and oxygen pressure are the major variables.

Explosion.—The sudden production of a large quantity of gas or vapor, usually hot, from a smaller amount of a gas, vapor, liquid, or solid. An explosion may be viewed as a rapid equilibration of a high-pressure gas with the environment; the equilibration must be so fast that the energy contained in the high-pressure gas is dissipated as a shock wave. Depending on the rate of energy release, an explosion can be categorized as a deflagration, a detonation, or a pressure rupture.

Explosive limits.—The maximum and minimum concentrations of vapor, mist, or dust in air or oxygen at which explosions occur. The limits are controlled by the size and geometry of the environment as well as by the concentration of the fuel. Detonation limit is sometimes used as a synonym for explosive limit.

Explosive reaction.—A chemical reaction wherein any chemical compound or mechanical mixture, when ignited, undergoes a very rapid combustion or decomposition, releasing large volumes of highly heated gases that exert pressure on the surrounding medium; a mechanical reaction in which failure of the container causes the sudden release of pressure from within a pressure vessel

Explosive yield.—The amount of energy released in an explosion. Explosive yield is often expressed as a percent or fraction of the energy that would be released by the same mass of a standard highly explosive substance such as TNT.

Flammability limits.—The maximum and minimum concentrations of a fuel (gas or vapor) in an oxidizer (gas or vapor) at which flame propagation can occur

Free air or free gas (STP).—Air or gas measured at a temperature of 60 °F (15.6 °C) and a pressure of 14.7 psia (101.4 kPa).

Glenn Research Center (GRC)

Hazardous (classified) location.—A location where fire or explosion hazards may exist because of flammable gases or vapors, flammable liquids, combustible dust, or easily ignitable fibers or flyings

Ignitable mixture.—A mixture that can propagate a flame away from the source of ignition

Ignition energy.—The amount of energy needed to initiate flame propagation through a combustible mixture. The minimum ignition energy is the minimum energy required for the ignition of a particular flammable mixture at a specified temperature and pressure.

Ignition temperature.—The temperature required to ignite a substance by using an ignition source such as a spark or flame

Intrinsically safe system.—A circuit in which any spark or thermal effect is incapable of causing ignition of a mixture of flammable or combustible material in air under prescribed test conditions and which may be used in hazardous National Electric Code (NEC)-classified locations.

Lower explosive limit (LEL).—The minimum concentration of a combustible/ flammable gas or vapor in air (usually expressed in percent by volume at sea level) that will explode if an ignition source is present

Lower flammable limit (LFL).—The minimum concentration of a combustible/ flammable gas or vapor in air (usually expressed in percent by volume at sea level at temperatures up to 121 °C) that will ignite if an ignition source is present

NASA Aerospace Safety Research and Data Institute (ASRDI)

NASA Procedural Requirement (NPR)

NASA Policy Directive (NPD)

NASA Safety and Mission Assurance (SMA)

NASA Safety Standard (NSS)

NASA Safety Training Center (NSTC)

National Electric Code (NEC)

National Fire Protection Agency (NFPA)

Nondestructive examination (NDE)

Nonvolatile residue (NVR)

Office of Protective Services (PSO)

Plum Brook Station (PBS)

Pressure Vessels and Pressurized Systems (PV/S)

Safety and Health Division (SHeD)

Safety, Health and Environmental Training (SHET)

Shock wave.—A surface or sheet of discontinuity set up in a supersonic field of flow, through which the fluid undergoes a finite decrease in velocity accompanied by a marked increase in pressure, density, temperature, and entropy, as occurs in a supersonic flow about a body

Stoichiometric combustion.—The burning of fuel and oxidizer in the exact proportions required for a complete reaction to give a set of products

Unconfined vapor cloud explosion.—Explosion that results from a quantity of fuel having been released to the atmosphere as a vapor or aerosol, mixed with air, and then ignited by some source

Vapor explosion.—A shock wave produced by the sudden vaporization of a superheated liquid coming into contact with a cold liquid.

White Sands Test Facility (WSTF)

APPENDIX B.—TABLES

TABLE B.1.—SELECTED SAFETY-RELEVANT PHYSICAL PROPERTIES OF GASEOUS AND LIQUID OXYGEN
[From Roder and Weber 1972; CGA Pamphlet G 4, 1996; and CRC Handbook of Chemistry and Physics.]

Reference temperature, F [R] (K)	68°	[527.7°]	(293.15°)
Standard pressure (1 atm), psia (kPa abs)	14.69	(101.325)	
Density,(a) lb/ft^3 (kg/m^3)	0.0831	(1.33)	
Specific volume,(a) ft3/lb (m^3/kg)	12.03	(0.751)	
Specific heat,(a) Cp, Btu/lb-F (J/g-C)	0.220	(0.919)	
Cv, Btu/lb-F (J/g-C)	0.157	(0.68)	
Velocity of sound,(a) ft/sec (m/sec)	1070	(326)	
Critical density, lb/ft3 (kg/m^3)	27.2	(436.1)	
Critical pressure, psia (kPa abs)	731.4	(5043)	
Critical temperature, F [R] (K)	–181.43°	[278.3°]	(154.6°)

Vapor pressure at selected temperatures, psia (kPa)

268.6° R	588	(4052.0)	
259°	441	(3039.0)	
240°	294	(2026.5)	
216°	147	(1013.2)	
196°	73.5	(506.60	
175°	29.4	(202.64)	
162°	14.7	(1010.32)	
Boiling point at 1 atm, F [R] (K)	14.7	(101.32)	
Specific heat,(b) Cp, Btu/lb-R (J/g-K)	–297.3	[162.4]	(90.18)
Density,(b) lb/ft3 (kg/m^3	71.23	(1141)	
Cv, Btu/lb-R (J/g-K)	0.221	(0.93)	
Velocity of sound,(b) ft/sec (m/sec)	2963	(903)	
Heat of vaporization,(b) Btu/lb (J/g)	91.59	(213)	
Heat of fusion at triple point, Btu/lb (J/g)	5.98	(13.9)	
Triple point temperature, F [R] (K)	-361.8	[97.9]	(54.35)
Triple point pressure, psia (kPa)	0.022	(0.152)	

Notes:
At reference temperature and standard pressure (527.7 °R and 1 atm).
At 162.4° R and 1 atm.

TABLE B.2.—SOME RECOMMENDED MATERIALS FOR OXYGEN SERVICE[a]

[From Bond et al., 1983.]

Application	Low pressure[b]	High pressure[c]
Component bodies	Nickel alloy steel Stainless steel	Monel Inconel 718
Tubing and fittings	Copper Stainless steel Steel Aluminum Aluminum alloys	Monel Inconel 718
Internal parts	Stainless steel	Monel Inconel 718 Beryllium copper
Springs	Stainless steel	Beryllium copper Elgiloy Monel
Valve seats	Stainless steel	Gold or silver plated over Monel or Inconel 718
Valve balls	Stainless steel Tungsten carbide	Sapphire
Lubricants	Everlube 812 Microsel 100–1 and 200–1 Triolube 1175 Krytox 240AB and 240AC Braycote 3L–38RP	Batch/lot-tested Braycote 3L–38RP Batch/lot- tested Everlube 812 Krytox 240AC
O-seals and backup	TFE, Halon TFE Teflon Kel F Viton	Batch/lot-tested Viton Batch/lot-tested Teflon
Pressure vessels	Nickel steel Stainless steel Steel Aluminum alloys	Inconel 718

[a]This table lists materials for conservative design standards. Materials listed in the “Low pressure” column and other materials that are not listed may be suitable for more extreme environment oxygen service. Careful engineering analysis and rationale shall be used to select alternate materials.

[b]Nominally less than 1000 psi.

[c]Nominally greater than 1000 psi.

APPENDIX C.—FIRST AID FOR CONTACT WITH CRYOGENIC MATERIAL

(To Be Posted At Test Site)

Contact with liquid oxygen or its cold boiloff vapors can produce cryogenic burns (frostbite). Unprotected parts of the body should not be allowed to contact un-insulated pipes or vessels containing cryogenic fluids. The cold metal will cause the flesh to stick and tear. Treatment of frozen tissue requires medical supervision since incorrect first aid practices always aggravate the injury.

C.1 Exposure to Cryogenic Gases/Liquids

Cryogenic burns result when tissue comes into contact with cold gases, liquids, or their containers. Contact may result in skin chilling or true tissue freezing. Commonly, only small areas are involved, with injury to the outer layers of the skin.

Small quantities of cryogenic material may evaporate from the skin before actual freezing occurs. Such an injury typically produces a red area on the skin. More significant injury is caused by true freezing: the formation of crystals within and around the tissue cells. Frozen tissue always assumes a yellowish-white color, which persists until thawing occurs.

C.2 First Aid for Cryogen-Induced Injuries

Steps to prevent and emergency care for cryogen-induced injuries must be incorporated into safety standards and training programs for operations and emergency response. Personnel shall be knowledgeable about the risks of injury from cryogens.

Treatment of frozen tissue requires medical supervision since incorrect first aid practices always aggravate the injury. In the field, it is safest to do nothing other than cover the area, if possible, and to transport the injured person to a medical facility. Attempts to administer first aid for this condition will often be very harmful. Listed below are some important don’ts:

> ***NOTE:*** *Attempts to administer first aid for this condition will often be harmful. Here are some important don’ts:*

- Don’t remove frozen gloves, shoes, or clothing except in a slow, careful manner (skin may be pulled off inadvertently).
- Don’t massage the affected part.
- Don’t expose the affected part to temperatures exceeding 112 °F or temperatures lower than 100 °F.
- Don’t apply snow or ice to the affected area.
- Don’t use safety showers, eyewash fountains, or other sources of water because the water temperatures will almost certainly be incorrect and will aggravate the injury.
- Don’t apply ointments.

Although safety showers may be provided, they are exclusively for nonmedical purposes such as extinguishing fires or flushing acid. Safety showers should be tagged, “Not to be used for treatment of cryogen burns.”

APPENDIX D.—CLEANLINESS SPECIFICATION FOR GASEOUS/LIQUID OXYGEN SERVICE IN GLENN TEST FACILITY SYSTEMS

D.1 Scope of Specifications

This specification establishes the minimum requirements for system and component cleanliness for GRC test facility gaseous and liquid oxygen service. It reflects the requirements of KSC–C–123H, 1995; MSFC HDBK 527, Rev. F; JSC SN C 0005, Rev. A; and MSFC Spec 164B. It includes the acceptable minimum cleanliness, cleaning, packaging, and verification requirements.

Rigid procedures shall be followed in preparing, assembling, testing, and packaging components to assure cleanliness and to avoid the inherent danger of oxygen reacting with grease, oil, or other foreign matter. Any procedure not complying with this specification must be submitted to the Assurance Management Office, the area safety committee and the designated authority having jurisdiction (AHJ) for approval.

This specification does not preclude the supplier's responsibility for providing a product that meets the system performance requirements and acceptability for oxygen use. It shall be considered an integral part of the purchase agreement between the vendor and NASA GRC.

D.2 Requirements

D.2.1 Materials

All materials used shall have been previously determined to be compatible with oxygen and should be widely accepted throughout the aerospace industry. All materials shall be approved by the Glenn Assurance Management Office and/or the area safety committee.

D.2.2 Lubricants

Liquid oxygen is a powerful oxidizing agent, so a petroleum-based lubricant must not be used. Special lubricants, such as the fluorolubes or the perfluorocarbons that have been tested and found suitable for oxygen service, may be used. All lubricants shall be approved by the Glenn Assurance Management Office and/or the area safety committee.

D.2.3 Cleanliness

All component parts shall be free of burrs, chips, scale, slag, or foreign matter and shall be cleaned prior to assembly. Inspection for cleanliness shall consist of the following.

D.2.4 Visual Inspection

Visible contamination shall require recleaning of the surface. Discoloration due to welding will be permitted, providing no scale or rust is associated with the discoloration. Visual inspection aided by an ultraviolet light source (3200- to 3800-angstrom wavelength) shall show no evidence of fluorescence from contamination.

D.2.5 White Cloth Inspection

Surfaces shall be rubbed in two directions with a clean, lint-free white cloth. Any evidence of oil, rust, stain, scale, or foreign matter will be cause for rejection. The cloth may be examined under natural or ultraviolet light. Use of ultraviolet light (3200- to 3800-angstrom wavelength) shall show no evidence of fluorescence from contamination.

D.2.6 Solvent Rinse

Sufficient quantities of solvent rinse shall be used so as to yield 100 milliliters/square foot of internal surface area. The solvent rinse shall be performed by either sloshing or agitating the fluid around the inside surface of the components and straining it through a 5-micron (or finer) filter. Further instructions are found in ASTM MNL36, January 2000.

D.2.7 Assembly

The component parts shall be individually cleaned prior to assembly. Precautions shall be used during handling and assembly to preclude contamination of component parts. Final assembly and inspection shall be done in a laminar-airflow clean work area whenever possible.

D.2.8 Cleaning

Cleaning shall consist of the typical cleaning, rinsing, and drying procedures used throughout the aerospace industry:

1. Cleaning shall consist of a thorough flushing of all surfaces with aqueous detergent solutions.
2. Rinsing shall consist of a thorough rinsing and flushing with demineralized water, followed by rinsing and flushing with isopropyl alcohol.
3. Drying shall consist of blowing dry with filtered gaseous nitrogen or oil-free air.

D.2.9 Inspection

Inspection of cleaned components shall be performed by the solvent rinse method where possible. (This is generally done during the final cleaning stages and just prior to the drying operation.) The solvent shall be used at a rate of 100 milliliters per square foot of internal wetted surface area. (For all components having less than 1 square foot of internal wetted surface area, use 100 ml of solvent.) The solvent rinse shall be performed by either sloshing or agitating the fluid around the inside surface of the component to ensure dislodgment of particles. The rinse shall be poured through a filter sized to detect all particles greater than 100 microns. The assembled component, or any part thereof, shall be recleaned if it fails to pass the inspection(s).

The Glenn Project Assurance Office and/or area safety committee reserves the right to inspect the finished component for cleanliness.

D.2.10 Packaging

On finished components, seal all openings with appropriate blind flanges, plugs, or caps or securely tape polyethylene sheeting (at least 0.008-inch thick (0.20-millimeter)) to prevent contamination, making sure the tape does not touch any cleaned surface. Components shall then be double packed and sealed with polyethylene (0.006-inch thick minimum (0.15-millimeter)) before they are put into a shipping container. Pad sharp edges before packaging to preclude puncturing the package. Exercise care in packaging to prevent shredded or abraded polyethylene material from becoming a contaminant.

D.2.11 Verification

Finished components shall be affixed with a tag, label, or stamp showing that they meet the requirements specified herein for oxygen services.

TABLE D.1.—GRC ACCEPTANCE CRITERIA BASED ON KSC–C–123 (LEVEL 300–A)

(a) Solid particles.

Particle size, microns	Maximum number per 100-ml sample (Millipore test)
<100	Unlimited
100 to 250	93
251 to 300	3
>300	0

(b) Fibers.

Fiber length (up to 25 μm diameter), microns	Maximum number of 100-ml sample (Millipore test)
0 to 500	20
501 to 1000	3
1001 to 1875	>1875 None

(c) Nonvolatile residue.

Maximum residue, mg/ft^2 1.0

(d) Hydrocarbon limit.

Method result	Result
Ultraviolet light	No fluorescence
Infrared spectrophotometer	5 ppm hydrocarbon

(e) Total solids and fibers.

25 mg/ft^2 (maximum)

D.3 Pressure Gauges and Transducers

Pressure gauges and transducers represent a cleaning challenge because of the small, inaccessible internal passages. In general, customized equipment for flushing is required (e.g., small-diameter tubing to flush Bourdon tubes). Cleaning, inspection, and packaging of pressure gauges and transducers shall conform to the requirements of this specification. The following table lists the current GRC cleaning specifications for oxygen service gauges and transducers.

TABLE D.2.—OXYGEN-CLEANING SPECIFICATIONS FOR PRESSURE GAUGES AND TRANSDUCERS

(a) Oxygen-clean certification of pressure gauges and transducers.

Hydrocarbon contamination level in solvent wash with IR scan method	< 5 ppm of hydrocarbon in a 50 cubic cm sample
Visual borescope	No scale, heavy rust, or particles

(b) Particles.

Particle size, microns	Maximum number per square foot
<100	Unlimited
100 to 250	1073
251 to 500	27
>500	0

(c) Fibers.

Fiber length, microns (up to 25 microns) diameter	Maximum number per square foot
0 to 500	20

501 to 1000 1000 to 1875 >1875	3 1 0

APPENDIX E.—PROCEDURES FOR GASEOUS OXYGEN TUBE TRAILERS

E.1 Operational Requirements

E.1.1 NOTE

1. Only qualified/certified operators shall perform transfers. Operator certification is described in Section 6.1.
2. While in storage or transport, a properly secured tube trailer should be maintained with all valves in the closed position and with the tailpiece and sample port capped. Additionally, the trailer shall be grounded, wheels chocked, and doors securely shut.
3. A two-man buddy system shall always be in place as specified in Section 6.2.1 of this chapter.

E.1.2 CAUTION

1. All materials shall be compatible with oxygen use as described in Section 6.5.
2. Rapid pressurization must be avoided to prevent potential ignition and fire.
3. Oxygen cleanliness levels must always be maintained. A minor oversight in maintaining cleanliness at the trailer connection point can destroy safe cleanliness levels of the entire oxygen system.
4. All interconnecting components used for fill, purging, or withdrawal must be free of hydrocarbon and particulate contamination (this includes purge gases).

E.1.3 Tube Trailer Fill

1. Ground the trailer at the connector located on the bumper.
2. Secure the trailer doors with latches provided.
3. Chock/block trailer wheels. Also place a cone or sign at the front of the trailer to indicate that the trailer is connected to the manifold.
4. Put up the required barricades and signs.
5. Open the gauge isolation valve to ensure that the supply manifold has maintained pressure and is leak free. (If the manifold has leaked to atmospheric pressure, cease operations and contact the cryogenic maintenance COTR for proper evaluation and repair.)
6. Connect the approved transfer hose to the fill tailpiece and supply-side fitting. (Maintain cleanliness of the caps.)
7. Secure the transfer hose restraining cables to the eyelets provided.
8. Purge the transfer hose.
9. Leak-check the hose connections.
10. Open all tube isolation valves (equalize pressure slowly).
11. After the transfer hose has been purged and checked, stand clear of the transfer hose and slowly open the trailer manual fill valve.
12. Ensure that all personnel stand clear of the transfer hose; then slowly, completely open the main gas supply isolation valve (from source) to fill the trailer.

E.1.4 Post-Fill Shutdown

1. Close the main gas supply isolation valve (from source) to begin the shutdown and disconnect operations.
2. Close the trailer manual fill valve.
3. Open the transfer hose vent/purge valve and bleed to atmospheric condition (cap fitting).
4. Disconnect the transfer hose restraining cable.
5. Remove the transfer hose from the trailer and cap the hose and tailpiece ports. NOTE: If a sample is required, follow the checklist procedures. (Draw the sample gas from the sample panel only.)
6. Close all tube isolation valves (transfer is complete).
7. Remove the ground, and close the doors prior to moving the trailer.
8. Remove the barricades, warning signs, and wheel chocks.

E.1.5 Tube Trailer Withdrawal

1. Ground the trailer at the connector located on the bumper.
2. Secure the trailer doors with the latches provided.
3. Chock/block the trailer wheels. ALSO place a cone or sign at the front of the trailer to indicate that the trailer is connected to the manifold.
4. Put up the required barricades and signs.
5. Open the gauge isolation valve to ensure that the supply manifold has maintained pressure and is leak free. (If the manifold has leaked to atmospheric pressure, cease operations and contact the cryogenic maintenance COTR for proper evaluation.)
6. Connect the approved transfer hose to the trailer withdrawal tailpiece and receiving station.
7. Secure the transfer hose restraining cables to the eyelets provided.
8. Open all trailer tube isolation valves (equalize pressure slowly).
9. Leak-check the trailer manifold piping.
10. Open the receiving station main isolation valve.
11. Pressure-purge the transfer hose assembly and maintain 40 to 100 psi in the transfer line.
12. Leak-check the transfer hose connections.
13. Slightly open the manual withdrawal valve on the trailer (valve will expose a 1/8-inch bleed port when open a half turn).
14. Withdraw personnel from the area of transfer hoses.
15. Open the trailer emergency shutoff valve from the remote location.
16. Allow the oxygen receiving station pressure to reach the trailer pressure; then close the trailer emergency shutoff valve.
17. Fully open the trailer manual withdrawal valve (after a three-quarter turn, the valve will begin exposing the full seat area).
18. Open the trailer emergency shutoff valve from the remote location to withdraw oxygen for use.

E.1.6 Post-Withdrawal Shutdown

1. Close the trailer emergency shutoff valve from the remote location.

2. Close the receiving station main isolation valve.
3. Vent and purge the transfer hose to atmospheric pressure as specified in the area of use.
4. Close the trailer manual withdrawal valve.
5. Disconnect the transfer hose restraining cable.
6. Remove the transfer hose from the trailer and cap the hose and tailpiece ports. Keep the hose and caps oxygen-clean.
7. Close all tube isolation valves. (The transfer is secure.)
8. Remove the ground and close the doors prior to moving the trailer.
9. Remove the barricades, warning signs, and wheel chocks.