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Space systems — Oxygen safety

Part 6: Facility planning and implementation

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National foreword

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Partie 6: Planification et mise en oeuvre des équipements

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Foreword

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ISO 22538-6 was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

ISO 22538 consists of the following parts, under the general title *Space systems — Oxygen safety*:

— *Part 1: Design of oxygen systems and components*

— *Part 2: Selection of metallic materials for oxygen systems and components*

— *Part 3: Selection of non-metallic materials for oxygen systems and components*

— *Part 4: Hazards analyses for oxygen systems and components*

— *Part 5: Operational and emergency procedures*

— *Part 6: Facility planning and implementation*

Introduction

This part of ISO 22538 describes a process to ensure the protection and safety of personnel and equipment associated with oxygen systems and components.

Space systems — Oxygen safety —

Part 6:
Facility planning and implementation

1 Scope

This part of ISO 22538 describes a process to ensure the protection and safety of personnel and equipment associated with oxygen systems and components. This part of ISO 22538 applies to ground support equipment, launch vehicles and spacecraft.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 22538-5, *Space systems — Oxygen safety — Part 5: Operational and emergency procedures*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 22538-5 and the following apply.

3.1.1
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facing of masonry for protecting an embankment

3.2 Abbreviated terms

GOX	gaseous oxygen
LOX	liquid oxygen
NPSP	net positive suction pressure
NTP	normal temperature and pressure
TNT	trinitrotoluene

4 Planning and implementation

4.1 Planning

Because of the hazards associated with oxygen and oxygen-enriched air, planning for the protection and safety of personnel facilities and equipment shall start at the initial facility design stages.

4.2 Environmental review

An environmental review of liquid oxygen (LOX) and gaseous oxygen (GOX) facilities shall include an understanding of potential environmental effects and how they can be effectively controlled. Situations during transportation, storage, transfer, testing and vaporization, where life, health, environment and property may be exposed to substantial hazards, shall be considered. The probability of events occurring and causing spills, the nature of the spills and the risks of fires and explosions shall be included in the evaluation.

4.3 Vapour cloud dispersion

Vapour cloud dispersion studies shall be performed, taking into account evaporation rates, cold vapour stability, spill sizes and ground conditions. These studies include the effects of ignition under various stages of developing oxygen-enriched air-fuel mixtures.

4.4 Fire/explosive protection

Various techniques and methods have been developed to provide protection against fires and explosions:

a) containers sufficiently strong to withstand explosions;

b) venting methods to prevent vessel failures;

c) sufficient clearances and separations between oxygen containers and incompatible materials, storage tanks, plant equipment, buildings and property lines, so that any accident or malfunction has a minimum effect on facility personnel and public safety: these may include protective enclosures such as barricades or cell enclosures;

d) ignition and flame prevention techniques.

4.5 Quantity-distance relationships

Quantity-distance relationships are intended as a basic guide in choosing sites and separation distances. Quantity-distance criteria for bulk oxygen storage facilities are intended to provide protection from external fire exposure. Quantity-distance criteria for oxygen-fuel systems, however, are intended to reduce the effects of fire, explosion, fragmentation and detonation, by keeping the hazard source at a safe distance from people and facilities.

4.6 Facility design guidelines

Some general facility design guidelines for oxygen facilities are as follows:

a) with a view to managing fires, provide an automatic remote shut-off to isolate critical components from all bulk oxygen supplies; water spray systems shall be provided;

b) locate oxygen systems a safe distance from heat or radiation sources;

c) limit ignition sources and provide lightning protection in the form of lightning rods, aerial cable and suitably connected ground rods in all preparation, storage and use areas; all equipment in buildings shall be interconnected and grounded to prevent inducing sparks between equipment during lightning strikes;

d) provide an isolation valve outside of a building that has oxygen lines to close off the oxygen supply;

e) anticipate indirect oxygen exposure that may result from system failures;

f) avoid venting into confined spaces;

g) use the fewest number of joints possible for piping;

h) locate instrumentation and controls so that the system can be inspected, serviced and operated without preventing a hazard to personnel; lighting shall be provided for equipment inspection and safe personnel movement;

i) provide sufficient clearance for vehicles in structures over roads, driveways and accesses: roads, curves and driveways shall have sufficient width and radius to accommodate required vehicles; access shall be provided for the operation and maintenance of safety and control equipment; two exit routes shall be provided from all buildings and test cells;

j) consideration shall be given to the effect of an oxygen system location, use, size and criticality on the cost of cleaning and inspection procedures (see ISO 14952).

5 Hazards and reviews

5.1 Hazards

5.1.1 Compressor and pump malfunctions

Many compressor and pump malfunctions have resulted in ignition and fire. The best available materials of construction are often not completely compatible with oxygen and will burn under certain conditions. Problems with centrifugal pumps have included sufficient friction between the rotating parts and the casing to cause ignition, bearing failures and fires. Lubrication also presents problems. Bearing friction tends to vaporize LOX with subsequent failures. Pumps with LOX-lubricated bearings shall maintain liquid at the bearing to prevent friction. Sufficient net positive suction pressure (NPSP) shall be maintained to prevent cavitation. Consideration shall be given to the installation of a cavitation sensor or downstream thermocouple with anti-shutdown capability to enhance safety.

Shaft seals exposed to the atmosphere may condense water and cause pump failures because of ice formation. Installing a purge envelope around this area may prevent this damage from occurring. Pump systems shall have suction screens or filters to keep out particles and to maintain the required cleanliness. The clearance between rotating and stationary parts shall be sufficient to eliminate catching of materials. Suitable devices (strainers or filters) for arresting contaminants shall be fitted in the intake and discharge lines. The mesh gauge of the strainer or filter shall be smaller than the smallest clearances between impeller and casing. The filter and screen sizes in oxygen systems shall be specified by the engineering or safety personnel. The pumps, bearings, seals and screens shall be designed, engineered and cleaned specifically for LOX service.

5.1.2 Liquid oxygen and gaseous oxygen system failure

Regulator, valve and mechanical device malfunctions can cause fires and explosions. Piping and valves in vaporization systems may fail, causing injury and low-temperature exposures. Combustion of materials in oxygen may occur, resulting in extensive damage from fires and explosions. Valves and high-pressure regulators may fail, usually from improper operation or the presence of foreign materials. Adiabatic compression may cause sufficiently high temperatures to ignite soft goods or foreign materials. Regulators shall be placed in operation correctly, and all fittings and connections shall be cleaned for oxygen service. Components of oxygen systems shall be tested for safety and performance. The use of proper materials and suitable filters and screens, cleanliness, avoidance of galling in valves and quality control will limit system failures. Piping manifolds shall be sized to prevent excessive back pressure.

5.1.3 Test cell entrances

Every entrance into an operating test cell shall be considered dangerous. Authorized personnel shall enter only after conditions within the cell have been determined to be safe. Test cells and buildings in which combustible or explosive mixtures are present shall not be entered under any condition. Personnel shall be warned of the presence of oxygen-enriched areas that create combustible or explosive mixtures and high- or low-oxygen concentrations by using detectors, sensors and continuous sampling devices that operate both an audible and visible alarm. These warning systems shall be designed and installed to allow for proper operation of the test equipment, while at the same time provide adequate warning time to reduce the potential of exposure to possible hazards or hazardous conditions.

5.1.4 Liquid air

Impact-sensitive gels can form if liquid air forms on exposed surfaces of LOX lines and components and is allowed to drip onto a dirty floor.

5.2 Hazards analysis

5.2.1 Facility-level analysis

In addition to the component- and system-level hazards analysis discussed in ISO 22538-4, a facility-level hazards analysis shall be performed for each facility system or subsystem to identify areas indicating high probability of failures that would result in leakage, fires and explosions. The hazards analysis allows a better understanding of the basis for the safety requirements and emphasizes the need for compliance with established regulations.

5.2.2 Methods

Methods of performing hazards analyses include techniques such as fault hazard analysis and fault-tree analysis, in which undesirable events are evaluated and displayed, or a failure mode and effects analysis and single-barrier failure analysis, in which potential failures and the resulting effects (including ignition and combustion in oxygen-enriched atmospheres) on the safety of the systems are evaluated.

6 Storage systems

6.1 Bulk oxygen system

A bulk oxygen system may be defined as 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 566 m^3 of oxygen at normal temperature and pressure (NTP), 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.

6.2 GOX location

Bulk GOX storage systems shall be located above ground and outdoors, or shall be installed in a building of fire-resistive, non-combustible, or limited-combustible construction that is adequately vented and used for that purpose exclusively. Containers and associated equipment shall not be located beneath, or exposed by the failure of, electric power lines, piping containing any class of flammable or combustible liquids, or piping containing flammable gases. Where it is necessary to locate a bulk GOX system on ground lower than all classes of adjacent flammable or combustible liquid storage, suitable means shall be taken (such as diversion curbs or grading) to prevent accumulation of liquids under the bulk oxygen system.

6.3 Barriers

Non-combustible barriers shall be provided to deflect any accidental flow of LOX away from the site boundaries and control areas. Oxygen spills into public drainage systems shall be prevented. Manholes and cable ducts shall not be located in oxygen storage and test areas.

6.4 Mechanical devices, instruments and operating procedures

The system and component designs and installations shall restrict the presence of combustible materials. Items to be considered include mechanical devices, instruments and operating procedures. Mechanical devices include suitable fittings and connections, valves and valve outlet designs, transfer hoses, filters and check valves. Instruments include analysers to monitor oxygen purity and to detect leaks and spills. Operating procedures include purging with gaseous nitrogen (GN_2) before wetting with oxygen, attention to cleanliness requirements and quality control programs.

6.5 LOX location

Liquid oxygen installations shall be located at recommended distances from buildings, fuel storage facilities and piping, in order to provide minimum risks to personnel and equipment. An impermeable, non-combustible barrier shall be provided to deflect any accidental flow of oxygen liquid or vapour from hazardous equipment such as pumps, hot electrical equipment, or fuel lines that are immediately adjacent to the LOX or GOX lines and that could be splashed with a gaseous or liquid leak. LOX tanks shall be located away from oil lines and areas where hydrocarbons and fuels can accumulate. The tanks shall not be located on asphalt, and oily or contaminated soil shall be removed and replaced with concrete or crushed stone. The location and amount of nearby flammable liquid and fuel storage shall be reviewed frequently. Special care shall be taken to avoid LOX spillage entrance into drains or manholes. The openings shall be minimized to reduce the risk of LOX spillage entrance.

6.6 Storage tanks and impounding areas

Storage tanks and impounding areas shall be located far enough from property lines to prevent damage by radiant heat exposure and fragmentation to buildings and personnel located outside the plant property limits. Radiant heat densities shall be limited at the property lines to avoid damage to off-property structures. Ground slope modification, appropriately sized gullies and dikes, and barricades shall be used for protection of facilities adjacent to oxygen storage and use facilities. Oxygen storage and use facilities shall be protected from failures of adjacent equipment (e.g. pumps), which could produce shrapnel. Liquid levels shall be maintained below 90 % of the volume of the storage tanks.

7 Storage vessels

In many instances, LOX storage vessels for ground support equipment are designed to serve as both storage and run tanks: as run tanks, they provide the oxygen directly into the test or flight equipment, without an intermediate vessel or liquid transfer operation. The design and construction requirements for such a combined storage-run tank are more demanding, since the pressure and flow requirements are usually considered greater than those for a storage vessel alone. Most large industrial oxygen users usually purchase liquid oxygen storage vessels from vendors who are familiar with low-temperature equipment design, fabrication and operation. The specifications shall be sufficiently detailed for a liquid oxygen storage system that is safe for long-term use. The design calculations shall take into consideration the intended use of the vessel and its storage and heat leak requirements.

8 Fire protection systems for oxygen-enriched environments

8.1 General

8.1.1 Operational personnel responsibilities

Because the combustion rate of materials in oxygen-enriched atmospheres is so greatly increased, response by professional fire fighters may not be quick enough to preclude major damage to a facility. For this reason, operational personnel in those oxygen-enriched environments shall be fully trained and instructed in the operation of the fire-fighting equipment provided. However, operational personnel shall not attempt to fight any major fires. Their mission is to secure the system as adequately as possible, notify the fire department and advise and direct qualified fire-fighting personnel as needed. The heightened level of oxygen fire volatility underlines the need to use highly-trained fire-fighting professionals. Extinguishing systems designed for the normal atmosphere may not be effective in an oxygen-enriched atmosphere.

8.1.2 Specifications

Rigid specifications for the design of fire-extinguishing systems for any planned or potential oxygen-enriched atmosphere have not been established. Each location shall have its own particular set of requirements. General guidelines have been delineated that will help set up a fire-extinguishing system for a particular use.

8.1.3 Evacuation plan

An evacuation plan for personnel in oxygen-enriched atmospheres shall be planned and the personnel shall be instructed. Quick evacuation is necessary to protect personnel from fire exposure, toxic gas exposure and extinguishing agent exposure. Easily visible evacuation route maps, including assembly points, shall be available in all working areas.

8.2 Fire-extinguishing systems

8.2.1 Automatic

It is recommended that fixed fire-extinguishing systems capable of automatic actuation by fire detection systems be established for locations containing oxygen-enriched environments. In such systems, the design emphasis shall be given to early detection, quick suppression system activation and evacuation of personnel. Where possible, detection systems shall concentrate on sensing fires as soon as possible, especially in the earliest stages of smouldering, before visible smoke or flames. Air-sampling particle detection systems have been used in this application to continuously monitor equipment and enclosed spaces. The extinguishing systems shall also provide rapid discharge, such as that used in deluge-type water sprays. Where protection of personnel is an issue, deluge systems shall be considered. It is up to the responsible authority to decide if the automatic system shall be kept in operation continuously during unoccupied periods. Areas left unattended for short time periods shall still have the automatic system in operation.

8.2.2 Manual

Manual fire-extinguishing systems can be used as a supplement to an automatic system. In some cases, small fires may be extinguished manually before actuation of an automatic system.

8.3 Fire-extinguishing agents

8.3.1 General

Depending on the location and application, personnel may work in oxygen-enriched atmospheres. Therefore, the use of specific fire-extinguishing agents shall be evaluated with respect to their inherent toxicity and the toxicity of breakdown products when used. Because of the increased combustibility and rapidity of burning materials in oxygen-enriched atmospheres, significant increases in water densities and gaseous concentrations of extinguishing mediums are necessary to extinguish fires. Although there are no standards for a minimum system design, the most effective general rule is to provide complete coverage with as much water or another acceptable extinguishing medium as is practically possible. In enclosed oxygen-enriched systems occupied by personnel, the toxicity of the extinguishing medium and the ability of personnel to evacuate with the suppression system operating shall be considered in the design.

8.3.2 Water

Water is the most effective extinguishing agent when sufficiently applied. A design using fixed water spray nozzles can be very effective.

8.3.3 Carbon dioxide

Only limited data exist regarding the effectiveness of carbon dioxide in extinguishing fires in oxygen-enriched atmospheres. Total flooding of an entire space is impractical because of the hazards to personnel from asphyxiation and toxicity.

8.3.4 Other agents

To avoid the problems with carbon dioxide and to use the advantages of a better effectiveness, the use of nitrogen, Halon, Novec 1230 and other agents should be considered.

9 Barricades

9.1 Need

Barricades needed in oxygen test areas to shield personnel, dewars and adjoining areas from blast waves or fragments resulting from a pressure vessel failure may also be needed to isolate liquid-oxygen storage areas from public or private property that may otherwise be too close.

9.2 Liquid or vapour travel

To control liquid and vapour travel caused by spills, the facility needs to include barricades, shields for diverting spills, or impoundment areas. Any loading areas and terrain below transfer piping needs to be graded toward a sump or impoundment area. The surfaces within these areas shall be cleaned of oils, greases, hydrocarbons and other materials, such as vegetation that can be easily ignited. Inspections shall be made to ensure good housekeeping.

9.3 Storage vessels

Barricades surrounding storage vessels shall be designed to contain 110 % of the LOX in the fully loaded vessel.

9.4 Types

The most common types of barricades are mounds and revetments. A mound is an artificial elevation of earth. It may have a crest at least 1 m wide, with the earth at the natural slope on each side and with such an elevation that projections from the structure containing the oxygen hazard to the structure to be protected will pass through the mound. A revetment is a mound modified by a retaining wall.

9.5 Studies and test results

Results of analytical studies and tests show that barricades reduce peak pressures and shock waves immediately behind the barricades. However, the blast wave can reform at some distance past the barricade. Revetments are more efficient than mounds in reducing peak pressures and impulses near the barricades.

Peak pressure and impulse are greatly influenced by the height above the ground, the location of the barricade and the barricade dimensions and configuration.

9.6 Pumps

Pumps are usually required at oxygen storage and use facilities, and protection against overpressures from liquid flash off and from pump failures yielding shrapnel shall be provided. Housings for high-rotational-speed test rigs may be designed as the shrapnel shield between the rig and the vessel. Guards shall be specified for exposed moving parts and for hot and cold surfaces.

9.7 Location of pressure vessels

When locating pressure vessels, consider the possibility of tank rupture causing impact to adjacent hardware. Shrapnel-proof barriers shall be used to prevent the propagation of an explosion from one tank to another, as well as to protect personnel and critical equipment.

10 Quantity-distance guidelines for bulk liquid oxygen storage

10.1 Criteria

The quantity-distance criteria for LOX shall be established.

10.2 Compatibility groups

Various compatibility groups have been developed, types of liquid propellants have been identified and the degree of hazard has been estimated. Liquid oxygen, for bulk storage conditions, is considered a Group II propellant hazard with a Group A storage compatibility designation.

NOTE Group II propellant hazards are strong oxidizers that exhibit properties such as vigorous oxidation or rapid combustion when in contact with materials such as organic matter.

10.3 Quantity-distance tables

The recommended separations of bulk oxygen storage systems from inhabited buildings and public traffic routes are shown in Table A.1 as non-mandatory and informative values. The intragroup incompatible and compatible Group II storage distances are also included in Table A.1.

10.4 Incompatible storage

When liquid oxygen storage and flow systems are part of the range launch pad, static test stand, or test area, a greater possibility of reaction with the fuel (propellant) exists. Potential reactions from leaks or pressure ruptures of propellant systems include normal combustion with the fuel or a detonation of the oxygen-fuel mixture. Therefore, with LOX in conjunction with a liquid fuel, as in engine static tests or launch operations, the quantity-distance criteria are based on blast hazards.

10.5 Explosive equivalent

10.5.1 Accidental release

A given total quantity of LOX plus fuel accidentally released and ignited can be expected to produce a blast-wave with far-field characteristics similar to some smaller amounts of high explosives. The total amount of propellants (fuel plus oxidizer) that are involved in an accidental release can be related to an equivalent amount of TNT or similar high explosive that would produce the same blast-wave, far-field overpressure. Liquid-propellant explosive equivalents for a few propellant combinations are given in Table A.2. The equivalent amount of explosive is determined by multiplying the explosive equivalent factor by the total weight, in pounds, of oxygen and fuel present.

10.5.2 Explosive equivalent factors

The explosive equivalent factors are considered extremely conservative. Results of theoretical studies and limited test results show that the equivalent weight numbers presently used for fuel-oxygen, such as hydrogen-oxygen and RP fuel-oxygen mixtures, indicate that maximum pressures as high as those that occur with trinitrotoluene (TNT) are not developed. The recommended separation distances shall be considered conservative. The total quantity of propellant in a tank, drum, cylinder, or other container shall be the net weight of the propellant contained therein. Where the storage containers are not separated by the appropriate distance, or are not so subdivided as to prevent possible accumulative involvement, the quantity shall be considered as the total of all such storage containers. The distances can be reduced with the installation of effective intervening barriers to limit or prevent mixing. The distance will be calculated on the basis of the explosive equivalent of the amounts, subject to the mixing.

10.6 Inhabited buildings and public traffic routes

10.6.1 Distances

Distances to inhabited buildings and to public traffic routes for various quantities of equivalent propellant mixtures are given in Table A.3. The factors outlined in 10.6.2 to 10.6.4 were considered in computing the distances.

10.6.2 Results of studies

Studies have shown that for small quantities of explosive mixtures and near-field distances, the fragment hazard is greater than blast hazard, but that for large quantities and far-field distances, fragments will not travel far because of air resistance, and blast becomes the principle hazard. This changeover phenomenon has been shown to happen at 13 608 kg. It is recommended that if an explosive mixture is mixed within a confined space such as a rocket motor or building that would produce fragments, a minimum distance of 183 m for equivalent quantities of 45 kg or less, or 381 m for quantities from 46 kg to 13 608 kg of equivalent mix weight, shall be used instead of the distances in Table A.3.

10.6.3 Safety

Designated safety personnel shall have initial approval authority for recommended separation distances.

10.6.4 Intraline distance

The 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. Indirect or delayed propagation may result from thrown fragments, debris, or firebrands. Serious personal injuries caused by fragments, debris, or firebrands are likely.

11 Quantity distance guidelines for bulk gaseous oxygen storage

11.1 General guidelines

The minimum non-mandatory distances from any bulk GOX storage container to exposures, measured in the most direct line, are as follows:

a) at least 15 m from buildings of wood-frame construction;

b) not less than 0,3 m (or other distance to permit system maintenance) from buildings of other than wood-frame construction;

c) at least 3 m from any opening in walls of adjacent structures: this provision shall apply to all elements of a bulk oxygen system where the oxygen storage is high-pressure gas; where the storage is liquid, this provision shall apply only to pressure regulators, safety devices, vaporizers, manifolds and interconnecting piping;

d) at least 15,2 m from solid materials that burn rapidly, such as excelsior or paper;

e) at least 7,6 m from solid materials that burn slowly, such as coal and heavy timber;

f) at least 22,9 m in one direction and 10,7 m at approximately 90° from confining walls (not including protective structures having a minimum fire resistance rating of 2 h) to provide adequate ventilation in courtyards and similar confining areas;

g) at least 15,2 m from places of public assembly;

h) at least 15,2 from areas occupied by non-ambulatory patients that are in a direct line from an inner container, a pressure relief device, discharge piping outlets, filling and vent connections, or a combination of these;

i) at least 3 m from any public sidewalk or parked vehicles;

j) at least 1,5 m from any line of adjoining property that may be built upon;

k) 7,5 m to 30 m from public facilities dependant upon the volume of GOX stored;

l) 5 m to 20 m from private houses dependant upon the volume of GOX stored;

m) at least 10 m from high pressure facilities from stored flammable gases; and

n) at least 8 m between a barricade and a flammable storage tank.

11.2 Protective structures

The distances in 11.1 a), 11.1 e), 11.1 i) and 11.1 j) do not apply where protective structures having a minimum fire resistance of 2 h interrupt the line of sight between uninsulated portions of the bulk oxygen storage installation and the exposure. A protective structure protects uninsulated oxygen storage containers or supports, control equipment enclosures and system piping (or parts thereof) from external fires. In such cases, the bulk oxygen installation shall be at least 0,3 m from the protective structure.

12 Oxygen detection

12.1 Decision making

Whether or not oxygen detectors are installed is a decision that shall be made at centre level. Considerations involved in making this decision shall include system construction and complexity, and the effects of system leaks on the facility or adjacent equipment. The installation of a detector system does not eliminate or reduce the requirement that a system shall be constructed leak-free and that it is inspected and validated at regular intervals.

12.2 Oxygen detection and monitoring system

A reliable oxygen detection and monitoring system shall have the properties outlined below.

a) It shall identify possible oxygen-enriched areas. While detection systems will not pinpoint a leak, they may or may not indicate the existence of one depending on wind or the detection method. Leak detection by observation alone is not adequate. Although the cloud and moisture that accompanies LOX leaks are visible, leak detection by observing such clouds is not reliable;

b) It shall give a warning whenever the worst allowable condition is exceeded. Visual alarms shall be considered for the systems to indicate that a problem exists.

12.3 Approval

Only detection units validated and approved by instrumentation personnel shall be used. The detection units and their response times shall be evaluated for suitable performance. Typical oxygen detection equipment used at test facilities includes the following (range from 0 to 25 and 0 to 100 percent by volume):

a) galvanic;

b) paramagnetic;

c) electrochemical (ZrO_2 sensor, fuel cell, open-cathode oxygen cell, polarographic);

d) gas chromatograph;

e) mass spectrometer.

12.4 Planning requirements

When planning an oxygen detection system, several steps shall be taken:

a) evaluate and list all possible sources to be monitored: valid justification shall be presented for any sources that are not considered for monitoring;

b) evaluate the expected response time of the oxygen detection system to ensure the compatibility of the fire detection or safety system considered for use;

c) include carefully maintained and periodically recalibrated detectors, as well as means to ensure that any leaking oxygen passing the detectors will be sensed;

d) consider the oxygen detection system with the fire detection and other safety systems used, in order to initiate corrective actions in as short a time as possible.

12.5 Location requirements

Locations requiring consideration for detectors include:

a) leak sources where the possibility of fire shall be eliminated, such as valve complexes, buildings, containers and test equipment;

b) at LOX valves, outside LOX containers and at exposed LOX lines, although leaks from these sources may be allowed to diffuse into the atmosphere;

c) LOX leaks (best be detected by temperature-monitoring systems) through vacuum-jacketed equipment: when it has been established that a leak exists in a vacuum-insulated vessel, the first step is to analyse the discharge of the vacuum pump with an oxygen analyser to determine whether the leak is in the outer casing or in the liquid container; if the analysis shows a normal purity of approximately 21 volume percent oxygen, the leak into the vacuum space is from the atmosphere.

13 Venting and disposal systems

13.1 Liquid oxygen disposal

13.1.1 Uncontaminated LOX

Uncontaminated LOX shall be disposed of by contained vaporization systems. It shall not be dumped on the ground because organic materials, e.g. macadam or asphalt, may be present. Recommended vaporization systems include:

a) direct-contact steam vaporizers in which LOX is mixed with steam in open-ended vessels: the vaporized liquid is ejected from the top of the vessel along with entrained air and condensed steam;

b) heat sink vaporizers, which are large containers filled with clean gravel and covered to exclude atmospheric contamination: the capacity of this type of vaporizer is limited to the sensible heat of the gravel.

13.1.2 Contaminated LOX

A problem with liquid-oxygen disposal is the concentration of relatively small quantities of dissolved hydrocarbons caused by preferential vaporization of oxygen. When LOX has been contaminated by fuel, isolate the area from ignition sources and evacuate personnel. Allow the oxygen to evaporate and the residual fuel gel to achieve ambient temperature. The hazard associated with this impact-sensitive gel is long-lasting and difficult to assess. Inert the oxygen system thoroughly with gaseous nitrogen before conducting any other cleanup step.

13.2 Gaseous oxygen (vapour) venting

13.2.1 Unobstructed venting systems

All dewar, storage and flow systems shall be equipped with unobstructed venting systems. Oxygen venting and dumping shall be restricted to concentrations that are safe for personnel at all directions and distances. A complete operations and failure mode analysis shall provide the basis for determining such conditions.

13.2.2 Design

Interconnecting vent discharges to the same vent stack may overpressurize parts of the vent system. The vent system shall be designed to handle the flows from all discharges, or it may produce backpressure in other parts of the system. Because these devices detect a differential pressure, inadequate designs may effectively change the release pressure on all pressure-relief valves and rupture disks connected to the vent system.

13.2.3 Vent discharges

High-pressure, high-capacity vent discharges and low-pressure vent discharges shall not be connected to the same vent stack unless the vent capacity is sufficient to avoid overpressurization of the weakest part of the system.

13.2.4 Distance from personnel

Venting shall be far enough from personnel areas to permit natural dilution to safe limits. Consideration shall be given for both oxygen enrichment and oxygen depletion, when venting inert gases from an oxygen system or when cleaning or purging the system. Before venting or relieving pressure, operating personnel shall be cleared from the area.

13.2.5 Vent-stack outlets

Vent-stack outlets shall be downwind from the prevailing wind direction, well removed from air intakes of test cells and control buildings, and away from walkways, platforms and traffic lanes. Large, scheduled discharges shall be performed when the wind direction is favourable.

13.2.6 Discharge to the outdoors

Discharges from all storage and transportation systems (from rupture disks and pressure relief valves) shall be to the outdoors through a vent line sized to carry the boil-off that would result from a total loss of insulation. Locate the oxygen vents at the highest possible point and exhaust the gas vertically. Venting into valve and pump operating enclosures will saturate the area and, in an emergency, the operators could be exposed to excessive hazards while attempting to control the equipment.

13.2.7 Protection from weather

The vent design shall provide protection from rain, snow and ice build-up. To restrict the entry and freezing of atmospheric water, outlets of small vent pipes shall be turned downward, and outlets of large vent stacks shall have caps. The use of tees is recommended for vent-stack outlets. Screens shall be mounted over vent openings to prevent insects or birds from building nests that will block the opening. A low-point drip leg shall be incorporated into vent-stack designs with vent-line plumbing and valves oriented to drop towards a collection area. All probable sources of water entry shall be controlled in this manner to prevent freezing components, which will make this safety system inoperable.

13.2.8 Characteristics of materials

Materials used in disposal and vent systems shall be corrosion-resistant and maintained at the required cleanliness level.

Annex A
(informative)

Tables

Table A.1 is taken from Reference [5], Table 9-19.

Distances to inhabited buildings, railroads, highways and incompatible storage were selected as 75 % of Group III inhabited building distances. They were considered reasonable because of the lesser hazard. When incompatible propellants are not separated by required distance or provisions are not made to prevent their mixing, the combined quantity of the two shall be used. See Table A.2 to determine if explosive equivalents apply.

Distances to intragroup (intraline) and compatible storage average 37,5 % of inhabited building distances listed in Reference [6].

Table A.1 — Safe quantity-distance relationships for liquid-oxygen storage

Mass of LOX kg	Distance to inhabited buildings, railroads, highways and incompatible storage m	Distance to intragroup (intraline) and compatible storage m
45	18	9
91	23	11
136	26	12
181	27	14
227	30	15
272	30	15
318	32	17
363	34	17
408	35	18
454	37	18
907	40	20
1 361	44	21
1 814	46	23
2 268	49	24
2 722	50	24
3 175	52	26
3 629	53	26
4 082	53	27
4 536	55	27
6 804	59	29
9 072	62	30
11 340	66	32
13 608	67	34

Table A.1 (*continued*)

Mass of LOX kg	Distance to inhabited buildings, railroads, highways and incompatible storage m	Distance to intragroup (intraline) and compatible storage m
15 876	69	34
18 144	70	35
20 412	72	37
22 680	73	37
27 215	76	38
31 751	78	40
36 287	79	40
40 823	81	41
45 359	82	41
56 699	87	43
65 385	90	44
79 378	93	46
90 718	94	47
113 398	98	49
136 077	101	50
158 757	104	52
181 436	107	53
204 116	108	55
226 795	110	55
272 154	114	56
317 513	117	58
362 872	120	59
408 231	123	61
453 590	125	62
907 180[a]	143	72
1 360 770[a]	154	78
1 814 360[a]	163	81
2 267 950[a]	169	84
2 721 540[a]	174	87
3 175 130[a]	178	90
3 628 720[a]	183	91
4 082 310[a]	186	93
4 535 900[a]	189	94

[a] Extrapolations above 453 590 kg levels extend well outside available data, but are supported by independent calculations and knowledge of similar phenomena.

Table A.2 is taken from Reference [5], Table 9-17.

The percentage factors given in Table A.2 are to be used to determine the equivalencies of propellant mixtures at static test stands and range launch pads when propellants are located above ground and are unconfined except for their tankage. Other configurations shall be considered on an individual basis to determine the equivalents.

The explosive equivalent weight calculated by the use of Table A.2 shall be added to any non-nuclear explosives weight aboard, before distance can be determined from Table A.3.

These equivalencies also apply when the following substitutions are made:

a) alcohols or other hydrocarbons may be substitutes for RP-1;

b) C_2H_4O may be substituted for any propellant.

Use LOX/RP-1 distances for pentaborane plus a fuel and LOX/LH_2 distances for pentaborane plus an oxidizer.

For quantities of propellant up to but not over the equivalent of 45 kg explosives, the distance shall be determined on an individual basis by the controlling organization. All personnel and facilities, whether involved in the operation or not, shall be protected adequately by proper operating procedures, equipment design, shielding, barricading, or other suitable means.

Distances less than intraline are not specified. When a number of prepackaged liquid propellant units are stored together, separation distance to other storage facilities shall be on an individual basis, taking into consideration normal hazard classification procedures.

Table A.2 — Liquid propellant explosive equivalents

Propellant combinations	Static test stands	Range launch
LOX/LH_2 or B_5H_9 + an oxidizer	60 %	60 %
LOX/LH_2 + LOX/RP-1	Sum of 60 % for LOX/LH_2 and 10 % for LOX/RP-1	Sum of 60 % for LOX/LH_2 and 10 % for LOX/RP-1
LOX/RP-1, LOX/NH_3 or B_5H_9 + a fuel	10 %	20 % up to 226 795 kg and 10 % over 226 795 kg

Table A.3 is taken from Reference [5], Table 9-1, Footnotes 3 and 7.

Table A.3 — Separation distances for liquid hydrogen-LOX propellant combination

Mass of explosive kg	Distance from potential explosion site	
	To inhabited buildings m	To public traffic routes m
0	12	7
1	15	9
2	21	12
4	27	16
9	34	20
14	38	23
18	43	25

Table A.3 (*continued*)

Mass of explosive kg	Distance from potential explosion site	
	To inhabited buildings m	To public traffic routes m
23	46	27
45[a]	58	35
91	72	43
136	82	49
181	90	53
227	98	52
272	104	62
318	108	66
363	114	69
408	119	72
454	122	73
680	140	84
907	154	93
1 361	177	107
1 814	194	116
2 268	209	125
2 722	223	134
3 175	235	140
3 629	244	146
4 082	255	152
4 536	264	158
6 804	302	181
9 072	332	200
11 340	357	213
13 608	381	227
15 876	399	239
17 436	418	250
20 412	434	261
22 680	450	270
24 947	463	277
27 215	477	287
29 483	491	294
31 371	503	302
34 019	514	308
36 287	526	315
38 555	536	322
40 823	547	328
43 091	556	334

Table A.3 (*continued*)

Mass of explosive kg	Distance from potential explosion site	
	To inhabited buildings m	To public traffic routes m
45 359	565	340
49 895	597	358
54 431	629	378
56 699	645	387
58 967	660	396
63 503	687	413
68 039	716	430
72 575	742	445
77 110	768	462
77 378	782	469
81 646	794	477
86 182	820	492
90 718	844	506
102 058	904	543
113 398	960	576
124 737	991	594
136 077	1 020	611
147 417	1 049	629
158 757	1 074	645
170 096	1 099	660
181 436	1 123	674
192 776	1 146	686
204 116	1 167	701
215 455	1 189	713
226 745	1 210	725

[a] For quantities of propellant up to but not over the equivalent of 45 kg of explosives, distance can be determined on an individual basis by the controlling organization. All personnel and facilities, whether involved in operations or not, shall be protected adequately by proper operating procedures, equipment design, shielding, barricading, or other means.

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