INTERNATIONAL STANDARD

ISO 22538-5

First edition
2010-07-01

Space systems — Oxygen safety —

Part 5: Operational and emergency procedures

Systèmes spatiaux — Sécurité des systèmes d'oxygène —

Partie 5: Procédures de fonctionnement et d'urgence

Reference number
ISO 22538-5:2010(E)

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Foreword

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ISO 22538-5 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*

Space systems — Oxygen safety —

Part 5:
Operational and emergency procedures

1 Scope

This part of ISO 22538 specifies a set of operational and emergency procedures for the safe storage, handling and transfer of liquid and gaseous oxygen.

2 Terms, definitions and abbreviated terms

2.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1.1
oxygen-enriched atmosphere
gas mixture or liquid mixture that contains more than 25 volume percent oxygen

2.1.2
qualified technical personnel
person who, by virtue of education, training or experience, knows how to apply physical and chemical principles involved in the reactions between oxygen and other materials

EXAMPLE Engineers, chemists.

2.2 Abbreviated terms

GOX gaseous oxygen

LOX liquid oxygen

PPE personal protective equipment

SOP standard operational procedure

3 Operational procedures

3.1 General guidelines

Standard operational procedures (SOPs) shall be developed, with checklists as required. The SOPs shall be prepared by qualified technical personnel familiar with the work being done and be reviewed by personnel experienced the use of oxygen. SOPs for all hazardous operations shall be reviewed by the designated safety authority. Occupational health personnel shall be involved in the review cycle when operational procedures involve potential health hazards. The SOPs shall be implemented by line management. SOPs shall provide for the control of hazards to an acceptable risk and shall be reviewed annually for observance and improvement. The procedures shall include the following:

a) notification of the designated safety authority during hazardous operations;

b) protection of personnel;

c) prevention and detection of oxygen leaks;

d) elimination of ignition sources;

e) identification of proper safety control and hazard identification equipment;

f) priming gaseous oxygen (GOX) or liquid oxygen (LOX) containing equipment during installation and start-up.

The design of safe facilities and equipment shall consider human capabilities and the limitations of personnel responsible for operations.

3.2 Personnel

3.2.1 General

3.2.1.1 Consideration for the safety of personnel at and near oxygen storage and use facilities shall start in the earliest planning and design stages. Safety documentation shall describe the safety organization and comment specifically on the following:

— inspections;

— training;

— safety communications and meetings;

— operations safety and instruction manuals;

— accident investigations;

— safety instruction records.

Training shall familiarize personnel with the physical, chemical and hazardous properties of LOX and GOX, with personal protective equipment (PPE), with the correct operation of oxygen systems and with hazard recognition and control prevention.

3.2.1.2 The responsible user organization of the facility shall be notified of oxygen transport, loading and use operations. The user organization shall ensure that the safety equipment required at the operational site is present, operational and that all necessary support organizations, such as security, have been notified. Transportation of oxygen-loaded systems shall not be scheduled during peak traffic periods if possible.

3.2.1.3 Equipment failures caused by operator errors can result in fires, explosions, injury and extensive damage. Operators shall be trained for proper operations and kept informed of any changes in operating or safety procedures. The operators shall be qualified and certified for working with LOX and GOX. They shall also be trained in the corrective actions required in an accident. Personnel engaged in operations shall be advised of the hazards that may be encountered.

3.2.2 Confined space

3.2.2.1 Instruments used for determining oxygen enrichment or oxygen depletion shall be calibrated in accordance with the manufacturer's requirements specific for the instrument. Given that oxygen itself is silent, odourless and invisible, undetectable by the human senses, the oxygen content of a workspace environment is a critical safety concern and shall not be underestimated for the following reasons:

— a slight reduction in the oxygen content of ambient air has physiological effects on exposed personnel: at low concentrations, it can incapacitate or even kill within minutes;

— a few percent increase in oxygen content increases flammability: without an effective detection/warning system, personnel are extremely vulnerable.

3.2.2.2 Personnel shall not be permitted to enter a confined space that may be subject to oxygen enrichment or oxygen depletion, or a confined space that contains a toxic material, until an assessment of that space is made and specific authorization is obtained. All personnel shall be aware of instrument limitations and cross-sensitivities to other contaminants. Entry shall be permitted in accordance with facility requirements and only trained personnel shall be allowed to use monitoring equipment, evaluate the possibility of access and actually enter the area. Free entrance is permissible only if the oxygen concentration is between 19,5 and 25,0 volume percent.

3.2.3 Operator certification

Before being certified to work with LOX or GOX, the operator shall demonstrate the following:

a) knowledge of the properties of LOX and GOX;

b) general knowledge of approved materials that are compatible with LOX and GOX under operating conditions;

c) familiarity with manufacturers' manuals detailing equipment operations;

d) proficiency in the use and care of protective equipment, clothing and safety equipment;

e) proficiency in maintaining a clean system and clean equipment in oxygen service;

f) recognition of normal operations and symptoms that indicate deviations from such operations;

g) conscientious following of instructions and checklist requirements.

3.2.4 Personal protective measures

3.2.4.1 General

Protective clothing and equipment, including respiratory protection, shall be included in personal protective measures. All operations that involve handling LOX shall be performed with a minimum of two members of staff (under the so-called “buddy system”) at the level required for the hazard and complexity of the task.

3.2.4.2 Safety clothing

3.2.4.2.1 Gloves for use around LOX systems shall not be made of leather and shall have a good insulating quality. They shall be designed for quick removal in case of infiltration by LOX. Because LOX may also infiltrate footwear, shoes shall have high tops, and trouser legs shall be worn outside and over the tops of shoes. The trousers shall have no external pocket openings and no cuffs. The shoes shall be of leather.

3.2.4.2.2 Personnel handling LOX shall wear head and face protection appropriate for the task. A face shield or a hood with a face shield shall be worn. If LOX is being handled in an open system, an apron of impermeable material shall be worn.

3.2.4.2.3 Oxygen will saturate normal clothing, rendering it extremely flammable. Clothing described as flame-resistant or flame-retardant under normal atmospheric conditions may be flammable in an oxygen-enriched atmosphere. Impermeable clothing components with good insulating properties may help protect the wearer from thermal injuries.

3.2.4.2.4 Any clothing that has been splashed or soaked with oxygen vapours shall not be removed until completely free of the gas. Personnel exposed to high-oxygen atmospheres shall leave the area and avoid all sources of ignition until the oxygen in their clothing dissipates. Oxygen can also saturate the skin, therefore personnel shall avoid ignition sources for 30 min after exposure.

3.2.4.3 Respiratory protection

If respiratory protection is required, as in cleaning, venting or purging operations, the breathing air used shall be periodically tested to ensure it meets required specifications. Cleaning, venting and purging operations may introduce chemical hazards, as well as oxygen deficiency or oxygen enrichment hazards. The breathing air shall be adequately characterized to ensure that the ambient air is safe to breathe. Respiratory protection shall be based upon this characterization.

3.2.4.4 Auxiliary equipment

3.2.4.4.1 Portable oxygen detectors of approved design are useful where oxygen leakage may increase fire and explosion hazards.

3.2.4.4.2 Safety showers and eye-wash fountains are provided only to deal with fire and corrosive chemicals or to flush cryogenic liquids from clothing and skin.

3.2.4.4.3 Water hoses shall be available to thaw valves and fittings on cryogenic storage containers. Atmospheric moisture may freeze on valve stems and similar components, making them impossible to open or close. Running water onto the frozen part may thaw the ice and enable component operation. Running water is also useful to thaw ice if a person's gloved hand freezes to a valve handle.

3.2.4.4.4 Appropriate warning systems shall be used to monitor oxygen systems that are a potential danger to operating personnel. The warning systems shall be shielded and designed in such a way that the operation of a single detection device serves to alarm, but not necessarily to initiate, basic fire and emergency protection. System and equipment safety components shall be installed for control of automatic equipment in order to reduce the hazards indicated by the warning systems. Manual controls within the system shall include automatic limiting devices to prevent overranging.

3.3 Cool-down and loading procedures

3.3.1 General

Appropriate cool-down and loading procedures shall be followed to limit liquid geysering and large circumferential and radial temperature gradients in the piping. Liquid flow cools a pipe faster than comparable gas flow and non-uniform cooling may occur with two-phase flow. System failures can result from operational pressure surges. The procedures and checklists shall ensure operation sequencing to prevent pressure spikes.

3.3.2 Cryogenic cold-shock

Subjecting a newly assembled LOX system to cold shock by loading it with clean liquid nitrogen following final assembly is highly recommended. After the cryogenic cold-shock, the system shall be emptied of liquid nitrogen and warmed to ambient temperature. Bolts and threaded connections shall then be retorqued to prescribed values and gas-leak-checking procedures shall follow.

Following cold-shock, the entire system shall be inspected for evidence of cracking, distortion or any other anomaly, with special attention directed to welds. System cleanliness shall then be checked and verified.

3.3.3 Hydrostatic testing

Where cleaning requirements preclude post-hydrostatic testing of a cold-shocked system, a thorough review of system integrity shall be conducted. This includes cases where a previously tested system is to be modified.

3.4 Examinations

A visual safety examination of the oxygen systems shall include verification of dimensions, joint preparations, alignment, welding or joining, supports, assembly and erection, and checking for conditions such as the following:

- corrosion (especially under insulation);
- mechanical damage;
- cracking (especially at welds and areas of known stress concentration);
- bulges or blisters;
- leakage;
- loose nuts, bolts, or other parts;
- excessive vibration;
- abnormal noise;
- excess temperature;
- discrepancies in gauge readings;
- pipe hanger condition;
- flexible hose anti-whip devices;
- frost on vacuum-jacketed lines and on containers;
- obstruction in relief-valve vents;
- evidence of contamination in system.

4 Emergency procedures

4.1 Types of emergencies

4.1.1 Leaks and spills

4.1.1.1 Primary danger

The primary danger from oxygen leaks and spills is a fire or explosion caused by combustible materials in the presence of a high concentration of oxygen. Oxygen-enriched environments greatly increase the rate of combustion of flammable materials. Just a few percent increase in oxygen content can increase flammability. This can happen rapidly in the event of a significant leak or spill, especially in a confined space. Without an effective detection/warning system, personnel are extremely vulnerable.

4.1.1.2 Gaseous oxygen

GOX leaks can result in oxygen-enriched environments, especially in confined spaces. Impingement of GOX onto an organic material such as grease can cause a fire. When leaks are detected, the source of the oxygen shall be halted or disconnected. Any equipment inherently heat-producing or spark-producing shall be turned off or disconnected. Disassembly and repair of leaking lines shall begin only after the area has been properly ventilated.

4.1.1.3 Liquid oxygen

IMPORTANT — GOX density is 1,1 (greater than that of air); 1 l of LOX vaporizes to more than 700 l of gas.

4.1.1.3.1 LOX spills and leaks cause oxygen enrichment of the immediate vicinity as the liquid vaporizes. When a spill or leak is detected, the source of the supply shall be immediately halted or disconnected. Any equipment inherently heat-producing or spark-producing shall be turned off or disconnected. Affected areas shall be completely roped off or otherwise controlled to limit the movement of personnel. The equipment or piping shall be thoroughly vented and warmed before repair of the leak is attempted.

4.1.1.3.2 LOX spills on pavements such as asphalt have resulted in impact-sensitive conditions causing explosions from traffic or dropped items. The same condition can occur from LOX leakage onto concrete that is contaminated with oil, grease or other organic materials. The affected areas shall be completely roped off or otherwise controlled to limit the movement of vehicles and personnel. Electrical sources shall be turned off or disconnected. No attempt shall be made to hose off the affected area, and the area shall not be cleared for access until the oxygen-rich cold materials are adequately warmed and absorbed oxygen has evaporated. Spilled LOX can quickly vaporize, obscuring the ground and creating potential slip/trip and fall hazards to personnel. This may also hinder safe evacuations in the event of an emergency.

4.1.1.3.3 LOX spillage entering drains and bunded or confined areas could result in temporary oxygen enrichment. The affected areas should be allowed to ventilate and should be controlled to limit access of personnel. Electrical sources should be turned off or disconnected. The area shall not be cleared for access until the oxygen-rich cold materials are adequately warmed and the absorbed oxygen has evaporated. Furthermore, the concentration of gaseous oxygen in the affected area shall be monitored with hand-held oxygen concentration monitors, and access shall be allowed only when the oxygen concentration returns to normal.

4.1.2 Overpressurization

4.1.2.1 Oxygen cannot be kept liquid if its temperature rises above the critical temperature of −118,6 °C. Consequently, if LOX is trapped in a closed system and allowed to warm, extreme pressures may overpressurize the system. For example, LOX trapped between valves may rupture the connecting pipe. Pressure relief of some kind shall be provided where trapping might occur. Moreover, relief and vent systems shall be sized to accommodate the flow so that excessive backpressures will not occur. Cryogenic liquid storage vessels are protected from overpressurization by a series of pressure-relief devices. These relief devices are designed to protect the inner vessel and the vacuum-insulated portion of the tank from failures caused by inner and outer shell damage, overfilling and heat load from insulation damage or from a fire.

4.1.2.2 In specific instances, such as when these vessels are involved in a fire which impinges upon the ullage area of the tank, container failure could result. In such cases, water shall be directed onto the flame-impinged portion of the tank to allow the tank to cool. Enough water shall be directed onto this area to keep the tank wet. Water shall not be directed toward the relief devices as the venting gas may cause the water to freeze and seal off the relief device.

4.1.2.3 Frost appearing on the outer wall of an insulated cryogenic vessel is indicative of vessel insulation loss. Frost appearance is only a clue to the type of insulation loss. This insulation loss could be caused by a movement of the insulation in the annular area of the tank, by loss of vacuum in the annular area, or by inner vessel failure. Assistance from knowledgeable and responsible pressure-system personnel shall be obtained, as outlined below.

a) Personnel shall listen and watch for indication of pressure-relief device actuation. Constant relief actuation is an indication that a major problem has occurred. Special care shall be taken if the sound of the relief device changes and becomes higher pitched while operating.

b) Continued pressure rise while the relief device is actuated indicates a major system malfunction. If constant relief device actuation occurs, immediately evacuate the area and physically rope off and control the area if this can be performed safely. Venting the vessel is recommended, if possible. Do not apply water, as this would only act as a heat source to the much colder oxygen and aggravate the boil-off.

4.1.3 Transportation emergencies

Vehicular accidents involving oxygen transports can result in leaks, spills and container rupture. Spills and leaks may result in fires and explosions. The first priority in an emergency situation is to protect personnel from hazards resulting from a spill or release of oxygen. The next priority is protecting property and the environment, which shall occur only after personal safety hazards have been mitigated.

Consult emergency response guidebooks and other references for information regarding the emergency action to be taken in the event of an accident involving LOX or GOX.

For packaging, storage or shipping of hazardous materials (e.g. compressed oxygen, LOX) see the European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR)[3].

4.1.4 Personal exposure to cryogenic liquid or cold vapour (cold injury)

Direct physical contact with LOX, cold vapour or cold equipment can cause serious tissue damage. Medical assistance shall be obtained as soon as possible for any cold injury. First-aid procedures to be administered by medical professionals are beyond the scope of this part of ISO 22538. However, proper immediate bystander response shall be as described below.

a) If it is safe to do so, remove the patient from the source of the cold.

b) In the event of limb-size or smaller cryogenic exposure, appropriate response may include an attempt to rapidly warm the affected area with moist heat from a shower, eyewash, or warm water bath not exceeding a temperature of 38,9 °C.

CAUTION — Do not allow a heavy stream of water to impinge directly on frozen skin. In some cases, it is safest to do nothing other than cover the involved area until professional medical help is available.

c) Massive full-body cryogenic exposures present significant additional concerns, but removal of the victim from the exposure atmosphere and keeping the victim's airway open are important. Loosely wrapping the victim in a blanket until the arrival of the ambulance team is also advised.

d) Respect the following rules:

   1) do not remove frozen gloves, shoes or clothing because salvageable skin may be pulled off inadvertently;

   2) do not massage the affected part;

   3) do not expose the affected part to temperatures higher than 44 °C, such as a heater or a fire, because this will superimpose a burn and further damage already injured tissues;

   4) do not apply snow or ice;

   5) do not apply ointments;

   6) do not allow any smoking, open flames or other hazardous conditions near the victim.

4.2 Assistance plans and procedures, and policy

4.2.1 Emergency plans

Each facility is responsible for the preparation of emergency plans and for implementing emergency procedures. These plans include evacuation routes as well as the requirements and responsibilities of site personnel. Dry runs of safety procedures shall be conducted using both equipment and personnel, and periodic safety inspections and surveys shall be performed in order to ensure that emergency procedures are being performed safely and that all safety equipment is operational. Fire drills, general safety meetings and facility inspections shall be held to develop and evaluate emergency plans and procedures.

4.2.2 Training

Familiarize training personnel with the physical, chemical and hazardous properties of LOX and GOX and with the nature of the facility's major process systems. Operator training shall include oxygen handling practice and emergency training in handling spills and fires. Supervisors shall keep operators informed of any operational or safety procedure changes.

4.2.3 Supervisors

Supervisors shall periodically monitor oxygen-handling operations to ensure that all safety precautions are taken during transfer, loading, testing and disposal. Local fire or other emergency personnel shall be informed of any unusual or unplanned operations. In addition, the accessibility and usability of PPE fire protection and spill response equipment shall be verified before liquid and gaseous oxygen-handling operations commence.

4.2.4 Written procedures

Written emergency procedures shall be included in all operating procedures involving LOX and GOX.

4.3 Fire-fighting techniques

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 well as possible, to notify the fire department and to advise and direct qualified fire-fighting personnel as necessary. The heightened level of oxygen fire volatility shall further emphasize the utilization of highly trained fire-fighting professionals. Extinguishing systems designed for the normal atmosphere may not be effective in an oxygen-enriched atmosphere.

When fighting a fire involving oxygen-enriched atmospheres, the first step is to shut off the oxygen supply and, if possible, to shut off and remove fuel sources. Combustible materials shall be cooled below their ignition temperatures to stop the fire. Water has been shown to be an effective extinguishing agent for fires involving oxygen-enriched atmospheres.

In some cases, when the oxygen supply cannot be shut off, the fire may burn so vigorously that containment and control are more prudent than trying to put out the fire.

If fuel and LOX are mixed but not burning, quickly isolate the area from ignition sources, evacuate personnel and allow the oxygen to evaporate. Mixtures of fuel and LOX are an extreme explosion hazard.

If a fire is supported by LOX flowing into large quantities of fuel, shut off the oxygen flow. After the excess oxygen is depleted, put out the fire with the extinguishing agent recommended for the particular fuel.

If a fire is supported by fuel flowing into large quantities of LOX, shut off the fuel flow and allow the fire to burn out. If other combustible material in the area is burning, water streams or fogs may be used to control the fires.

If large pools of oxygen and water-soluble fuels, such as hydrazine or alcohol, are burning, carefully spray low-pressure water on the pool to dilute the fuel and reduce the fire's intensity.

Bibliography

[1] ISO 22538-2, *Space systems — Oxygen safety — Part 2: Selection of metallic materials for oxygen systems and components*

[2] ISO 22538-3, *Space systems — Oxygen safety — Part 3: Selection of non-metallic materials for oxygen systems and components*

[3] European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR)

ICS 49.140

Price based on 9 pages