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AIR LIQUIDE ENGINEERING TECHNICAL COMMISSION	DESIGN SAFETY RECOMMENDATION	DSR - B-10-01-(0) Page : 1/21

GASEOUS OXYGEN PIPING PROTECTIVE BARRIERS

Supersedes :

Summary :

The purpose of this DSR is to define in which case a permanent passive barrier around an oxygen piping system is required as well as the minimum necessary design requirements related to safety. It completes the barrier requirements given in DSR-B-02-04 ("Gaseous Oxygen Piping"). Concrete walls are strongly recommended. Nevertheless the design rules given in this document are applicable for any type of fire/ fragment barrier.

Issue	Date	Modified pages	Remarks
0	25.06.03	New document	

Prepared by : ETC and K Dunleavy Visa : Approved by : Christian PUECH On : July 8th, 2003 Visa :	**Reading committee :** Refer to READING COMMITTEE list enclosed. **Owner :** Engineering Technical Commission
File : DSR-B-10-01-(0)	Enforced on : 15.07.03

GASEOUS OXYGEN PIPING PROTECTIVE BARRIERS

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GASEOUS OXYGEN PIPING PROTECTIVE BARRIERS

FOREWORD

Subject to any and all applicable national and local laws, rules and regulations, the following recommendations apply to all new installations. To the extent that national and local laws, rules and regulations are less restrictive, consideration should be given to the practices listed in this DSR.

1 PURPOSE

The survey of past incidents shows that protective barriers have saved lives.

The purpose of this DSR is to define in which case a permanent passive barrier around an oxygen piping system is required as well as the minimum necessary design requirements related to safety. It completes the barrier requirements given in DSR-B-02-04 ("Gaseous Oxygen Piping").

2 FIELD OF APPLICATION

All Air Liquide divisions dealing with oxygen production plants and oxygen pipelines, whether Air Liquide or its subcontractors, must follow this DSR. This recommendation applies to the design of all new gaseous oxygen piping systems with:

- operating pressures between 0 and 200 bar abs,
- temperatures between -40°C and +100°C,
- oxygen purity up to 99.95%,
- dew point below -40°C.

These requirements are also applicable to temporary oxygen equipment.

At this stage, this DSR does not deal with requirements specific to oxygen compressor barriers. As a minimum guideline, CGA G.4.6 shall be used for oxygen compressors.

This recommendation is not intended for the following applications :

- Liquid (or cryogenic) oxygen
- Piping inside cold boxes and heat exchangers manifolds
- Compressors in oxygen service (including associated piping inside protective walls)
- Oxygen cylinder filling plants and breathing mixtures
- Hospital medical oxygen piping installations
- Piping on specialized equipment (such as jet piercing...)

3 REFERENCES

REF1	CGA G4.6	Oxygen Compressor Installation and Operation Guide
REF2	CGA G4.4	Industrial Practices for Gaseous Oxygen transmission and distribution piping systems
REF3	DSR B02.04	Design Requirements for Gaseous Oxygen Piping
REF4	NFPA-53	Recommended Practices on Materials, Equipment and Systems used in Oxygen Enriched Atmospheres
REF5	AL email dated on the 24th June 2002	Creation of the WWE & LI Oxygen Equipment Validation Team (Creation of the OEVT.doc)

REF6	OTI 92 603	Analysis of projectiles (British Health & Safety Executive)
REF7	CPR 16^{E}	Methods for the determination of possible damage to people
REF8	AL report dated on the 23rd Sept 1981	CTPS report (Fire of the oxygen booster in South Africa - the 25th of June 1981) - CTPS meeting held the 1st of October 1981.

To the extent that the recommendations set forth herein are inconsistent with any of the above references, the recommendations set forth herein shall prevail unless otherwise required by law.

4 DEFINITIONS - ABBREVIATIONS

Barrier (from REF3) :

1 Physical item such as a protective shield or wall intended to prevent flames, molten metal, and piping fragments from injuring personnel and damaging adjacent equipment in case of a fire within the oxygen system.

2 Safety distance.

3 Measure, procedure or system used to prevent the occurrence of an event.

Barrier types 1 and 2 are passive barriers.

Fire barriers (derived from REF3) are screens or shields that protect personnel from injury or adjacent equipment damage. They shall block and contain an oxygen combustion lance and molten splatter caused by an oxygen fire where metal is a combustion fuel. Fire barriers are not intended to perform as fragment containment barriers even if they can impede equipment fragments with low kinetic energy.

Fragment barriers (from REF3) (or **Fragment/ Fire barriers**) are blast containment barriers that perform as a fire barrier as previously defined, but also block and contain any blast fragments. In this document, the fragments considered have a lower mass and kinetic energy than the ones considered for oxygen compressors. [1]

Oxygen piping system (from REF3) means all the stationary equipment in contact with gaseous oxygen used for its transportation and distribution. It includes pipes, fittings, valves, filters, strainers and instrumentation.

Oxygen equipment system means any piece of equipment like valves, filters, strainers or instrumentation excluding piping.

Overall Safety Distance is the distance beyond which the risk of injury by an oxygen fire is negligible. It is determined by the maximum distance covered by any projectile in case of oxygen fire.

Jet Safety Distance is the distance beyond which the risk of injury due to the jet effect, the flash fire or the oxygen enrichment in case of oxygen fire is negligible. This distance is always shorter than the Overall Safety Distance. It delimits the restricted area where people access is tolerated only with an approved procedure in the case of oxygen stations without walls.

[1] For centrifugal compressors, fragment characteristics to be considered are 30 kg at 50 m.s-1 (REF8).

5 PASSIVE BARRIER PURPOSE

A passive barrier (walls or safety distances) shall protect people and surrounding equipment against the consequences of an oxygen fire (flash fire[2], jet load[3], fragments and molten metal).

6 PASSIVE BARRIER SELECTION CRITERIA

- No passive barrier is required for oxygen equipment validated without barrier[4].
  When located in an unrestricted access area, it shall be at least protected by a fence with a locked door and "Authorized Personnel Only" and "No Smoking Area"[5] signs.

- Passive barriers are required in all other cases. Depending on the environment, walls and safety distances can be combined (e.g. oxygen station along a road in a field).

			Piece of equipment	
Equipment validation for oxygen service (as per REF3)		Barrier purpose	Manually operated	Remote controlled
Equipment validated for oxygen use **without** barrier			No barrier required	No barrier required
Equipment validated for oxygen use **with** barrier	Operation	To protect people when they operate a valve	Fire/ fragment barriers	Fire/ fragment barriers or safety distance
	Maintenance	To protect people when they do the maintenance of one line when the other is in operation	Fire/ fragment barrier between the two lines	Fire/ fragment barrier between the two lines
	Domino effect and surroundings	To protect surroundings (storage tanks, public areas...)	Fire/ fragment barriers or safety distance	Fire/ fragment barriers or safety distance
		To protect other adjacent oxygen isolation devices	Fire/ fragment barriers	Fire/ fragment barriers

In the particular case of a piece of equipment not yet validated for oxygen use but that has satisfactorily been used under oxygen service, the Designer shall ask a specialist, member of the

[2] Hot gas and splatter
[3] Jet load may knock down personnel in the area or destroy the walls
[4] The validation procedure is described in details in REF3 Appendix D
[5] In the native language

Oxygen Equipment Validation Team, for its proper installation (see REF5). (By default, rules defined for equipment validated for O2 use with barrier shall apply.)

6.1 PARTICULAR CASE OF FRAGMENT BARRIERS

Barriers that contain all projectiles without increasing the confinement risk are complex.

The survey of past incidents where walls have been concrete shows that:
- fragments have never caused people injury,
- most of them have been stopped by the walls,
- however some projectiles have been thrown outside the walls.

These few projectiles can be dangerous if they hit people or critical equipment (domino effect) with a sufficient energy.

Therefore areas where presence of people is permanent or areas with critical equipment shall not be exposed to projectiles:
- by using equipment validated for O2 use without barrier
- by installing the equipment in areas where presence of people or domino effect[6] can be neglected (by respecting the Overall Safety Distance or presence of obstacles consisting of equipment not subject to domino effect) (see § 8)
- by using partial roofs (refer to §7.1.2.4).

7 DESIGN RECOMMENDATIONS

7.1 FIRE/ FRAGMENT BARRIERS

7.1.1 Load

A wall shall support:
- Flame front
- Projection of molten metal
- Projection of fragments
- Jet load
- Wind and seismic loads (if applicable).

7.1.1.1 Flame front

Fire barrier should be made of concrete or equivalent.
This equivalence is given by the following test: the fire barrier shall be capable of completely blocking an oxygen combustion lance of approximately 5600°F (3100°C) for a minimum of 3 seconds with an oxygen lance (¾" nominal diameter burning bar from Oxylance Corp. or Paaso

[6] The risk of perforation of surrounding equipment by a projectile generated by an oxygen fire cannot be neglected (see examples in REF7).

General Equipment Inc. (PGE)) fed with 100 psig minimum and placed at 6 inches (15 cm) from the barrier[7].

7.1.1.2 Projection of molten metal or fragments

Based on the present knowledge, it is considered that a barrier sized according to the jet load formula given in § 7.1.1.3 will also block molten metal or fragments from an oxygen equipment fire.

7.1.1.3 Jet load

It shall be checked that the walls cannot be destroyed or overturned by the jet load.

The jet load F shall be calculated by using the following equation[8]:

$$F = 1.017 \times PD^2 - 0.81 \times D^2 \qquad \text{(F in daN; D in cm; P in bar abs)}$$

$$F = 0.997 \times PD^2 - 11.54 \times D^2 \qquad \text{(F in lbs; D in inch; P in psi)}$$

where D is pipe diameter ; P is nominal gas pressure

Exposed area (A) to be calculated by using the following formula:

$$A = \frac{\pi \cdot (D + 2 \cdot d \cdot \tan 10^{\circ})^2}{4}$$

where D is pipe diameter and d distance between the pipe and the wall.

The exposed area shall be centered on the wall.

The oxygen pipe axis shall be located below the center of the wall.

7.1.1.3.1 Exceptional case of exemption material equipment validated for use with barrier

If an exemption material equipment is exposed to ignition, it will not burn completely. By definition, an equipment made of exemption material cannot experience sustained combustion for pressures up to 200 bar (2900 psi) (low damage potential).

However, in special cases, the WWE & LI Oxygen Equipment Validation Team may still decide to put a wall. In this case the walls can be designed to support the jet load from the hole only (assume 25 mm diameter size and not the full diameter of the equipment)[9] provided that adjacent equipment / piping fulfills the arrangement requirements defined in chapter 9.2.2.2 of REF3.

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[7] Concrete complies with that condition, or 11 mm thick « Hardie Panel », James Hardie Building Products, Mission Viejo, California USA (indoor service), or ½" thick "Steelstone", AFI, Charlotte, North Carolina USA (indoor/outdoor service), or 10 mm thick DuraSystems "3DF2" sheet with galvanised steel, Durasystems Barriers Inc. Vaughan, Ontario, Canada (indoor/ outdoor service)

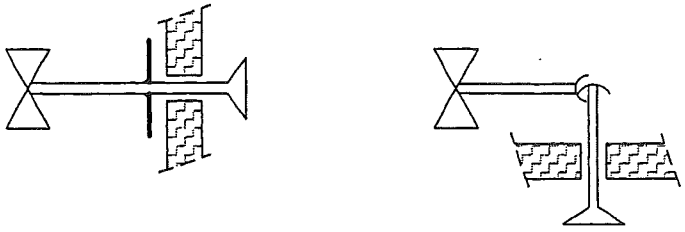
[8] This formula has been established by assumi ng an infinite source of pressure.

9 Refer to ASTM STP 986 page 385 Copper

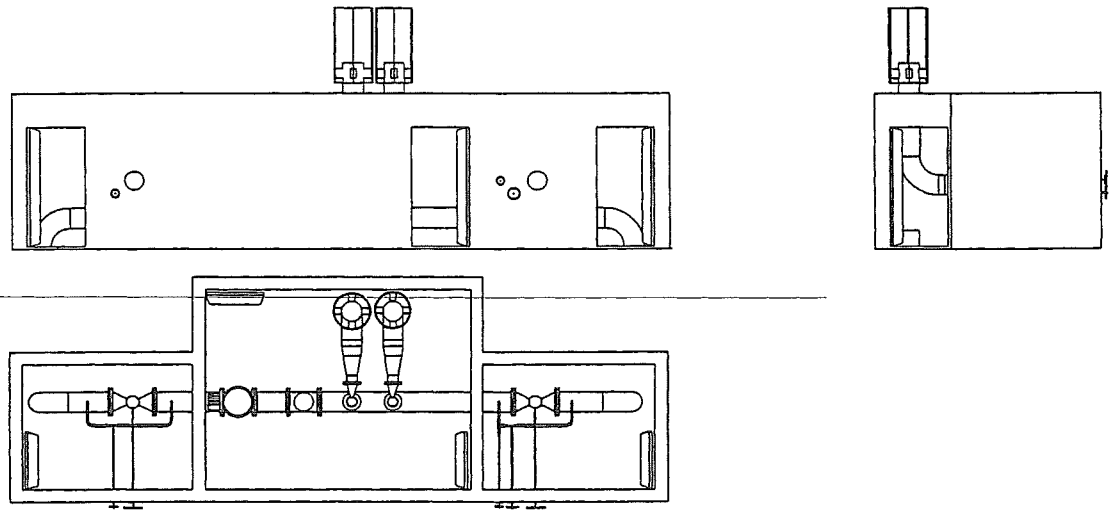
7.1.2 Layout

Oxygen piping systems must be engineered such that barriers can be applied.

When required (see table §6) walls shall be installed around the oxygen equipment to protect:
- the operator (in particular the hand wheel of a manual valve shall be outside the wall and equipped with an angle gear drive inside the walls or if the diameter is smaller than or equal to 2" a shielding disk welded on the stem inside the wall (see drawing here after)
- any isolation device(s) like isolation valves, check valves, emergency shut-off valves (to avoid domino effect in case of unconfined fire of the oxygen equipment)
- maintenance people (in case of operating adjacent area; e.g. two lines in parallel)
- the surroundings



Example:



7.1.2.1 Holes

The barrier should have no hole except for piping or equipment passing through, but in this case, the clearance between concrete and the penetration should be minimized. The gap between concrete and the penetration must be zero by using a asbestos-free fiber cement shield (Hardie® panel or AL approved equivalent) and fire stop mastic (Hilti CP618 or AL approved equivalent) preferably inside the walls.

Carbon steel shields are prohibited.

7.1.2.2 Height

Minimum height is 2.5 meters (8 feet) and at least 60 cm (2 feet) above the top of the highest component of the installation under pressure with exception of safety valve and vent exhausts. Check that the fire barrier blocks any line of sight view of any potential hazard from operational and maintenance location inside the Jet Safety Distance (see §7.2). Any plant area accessible to personnel must be considered.

7.1.2.3 Equipment outside the protective walls

Equipment that shall be located outside the walls include :

- all equipment subject to operator's control
- solenoids on control and isolation valves
- instrumentation readouts and equipment whose maintenance must be made during operation
- emergency shutdown switches
- sampling valves
- light switch (if any).

7.1.2.4 Roof

Full roofs are forbidden as they restrict:

- free air circulation in case of oxygen leak (oxygen enrichment)
- and pressure release in case of oxygen fire.

Partial roofs should only be considered in order to block potential fragments and be designed to allow natural ventilation and to stand the blast effect. They must block the directions of locations where fragment impact can cause potential major hazards (domino effect or permanent presence of people) inside the Overall Safety Distance (see sketch in Appendix F).

7.1.2.5 Access inside a walled station

Although labyrinths have been often used in the past, incident investigations have shown that particles and gas generated by an oxygen fire can ricochet up to areas considered as safe (see impact plotting in Appendix E).

Consequently doors are strongly recommended for walled oxygen equipment system. They also restrict efficiently the access to hazardous gaseous oxygen equipment. They shall be lockable in closed position.

The doors and their frame must be designed to withstand the jet load and the fire jet. If doors swing in, it must be made possible to wedge them open.

Maintenance should be designed so that it can be made from one side of the line. If maintenance requires to stand on both sides, one way of egress (escape exit) is required on each side. The distance between the way of egress and the farthest piece of equipment shall not exceed 5 m (15 ft).
When only one way of egress is there, it shall preferably be installed upstream the equipment.

If labyrinths are used instead of doors, they must be carefully designed to guarantee that any projectile will rebound at least three times[10] on walls prior to go outside (see Appendix G).

7.1.2.6 Ventilation

A natural ventilation against oxygen enrichment shall be ensured.

The absence of roof is sufficient to ensure the renewal of atmosphere by natural convection provided that no obstacle screens the oxygen station from the wind (buildings or other obstacles around the walls) and the ratio height/width of each cell of the station is close to one.

Natural renewal of atmosphere (even in quiet atmospheric conditions) may be estimated as follows: $Q = 1/10 * S * v$ (1)

where Q = Air renewal flow rate in m3/s
S = Surface of the smallest wall in m2
v = Wind velocity in m/s (to be taken = 1 m/s in quiet atmospheric conditions))

(1) As per Altran and Phast formula, confirmed by TNO (Netherlands Organization for Applied Scientific Research)

A mass flow calculation shows that the maximal allowable O2 leakage qM for maintaining less than 25% O2 atmosphere inside the station is:

$qM < 0.05 * Q$ qM : maximal allowable O2 leak flowrate in m3/s
Q = Air renewal flow rate in m3/s

Typical example: With a station 4mx3mx h 2.5m and a wind of 1 m/s:
Air renewal Q = 3*2.5*1*1/10 = 0.75 m3/s = 2700 m3/h
Maximum allowable leak $q_M <= 135$ m3/h when station is in service
Time necessary to decrease oxygen concentration from 100% to 25% when station is not in service = about 1 minute.

In case of partial roofs, they shall be designed to allow efficient natural ventilation and to stand the blast effect (see typical sketch in Appendix F).

A permanent sign with " Warning - Potential oxygen enriched area - Use portable analyzer" shall be installed close to the access.

Note 1: labyrinths which prevent projectiles from being thrown outside also restrict natural ventilation.
Note 2: entry into a walled gaseous oxygen equipment system requires oxygen analyzers with the doors kept opened (see 7.1.2.6).

7.1.2.7 Visual inspection from outside

Holes through the fire/ fragment barriers shall be minimized.

[10] Survey of past incidents has shown that many projectiles have rebound two times

However it can be made possible to visually check night and day the integrity of the oxygen equipment system protected by the walls before entering the station by the installation of a mirror at the top of the wall.

7.2 SAFETY DISTANCES

It is rational to say that a minimum distance exists beyond which people injury by an oxygen fire is impossible.

In principle, this distance should delimit an area where people access is restricted and may be used as an alternative to walls.

Practically, two distances shall be considered:

- the **Overall Safety Distance** (see Appendix A)
- the **Jet Safety Distance** (see Appendix B)

Overall Safety Distances can usually not be used to define the restricted area[11].

Where presence of people is unlikely within the area defined by the Overall Safety Distance (typically oxygen station in a uninhabited zone), a restricted area delimited with the Jet Safety Distance can be preferred to walls. In this case, the likelihood of people presence must be regularly checked within a radius equal to the Overall Safety Distance.

Note 1: remote controllers shall be located outside the restricted area or protected by a wall (refer to § 7.1.2.3).
Note 2: the oxygen enrichment distance (O2 content > 35%) in case of oxygen fire has been considered for different values of pressure and diameter; it is in the same range as the Jet Safety Distance. Consequently Jet Safety Distance is considered to cover the oxygen enrichment risk.

7.3 PROTECTION BY FENCE

Fence protect against unauthorized personal entry only.

Minimum height: 2.2 meters (7 feet)

Minimum distance between equipment and the fence:
- 1 meter (3 feet) for oxygen equipment validated without barrier
- Jet Safety Distance (as per §7.2) for oxygen equipment validated with barrier.

[11] For P=40 bar and DN=300, Overall Safety Distance > 200 meters.

7.4 SIGNAGE

For stations located outside AL plant property, the sign should indicate "Oxygen Station", with the reference of the pipeline operator and a telephone number where the pipeline operator can be reached in an emergency. Each station should also have a tag number or a name being referenced on a map (see also 7.1.2.6).

8 SITING

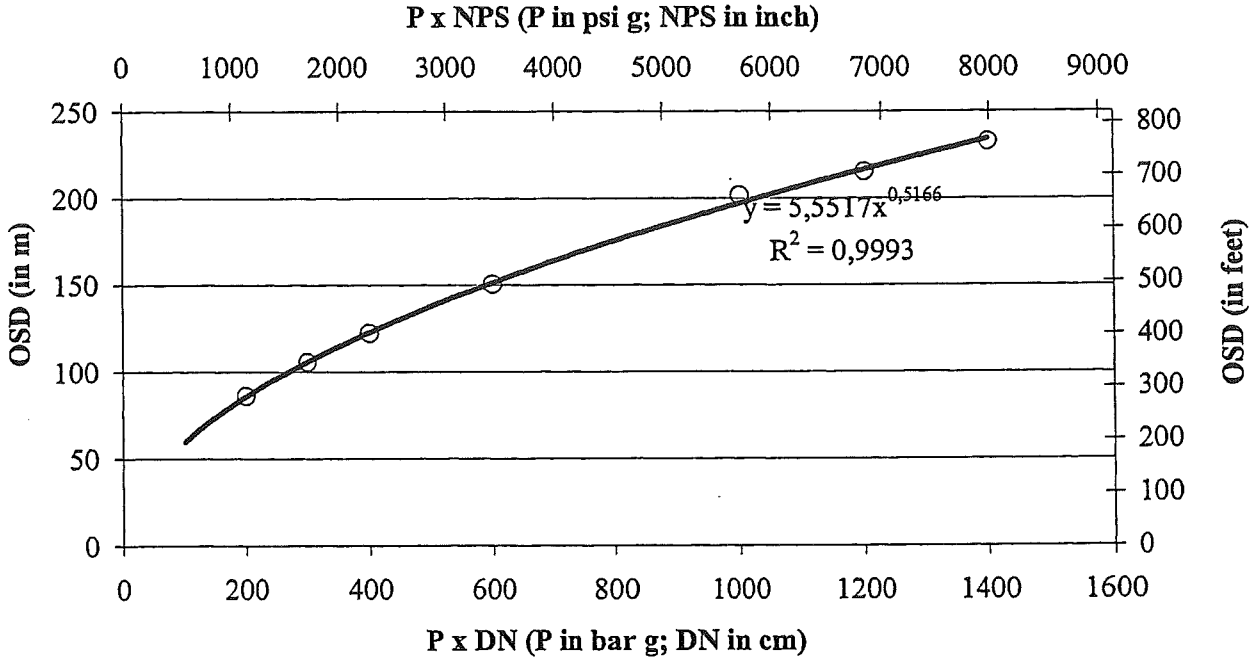
The Overall Safety Distance or walls equipped with a partial roof may only be considered for sensitive areas (hospital , school...) or permanent presence of people (offices...) or critical equipment such as large cryogenic liquid storage tank or distillation columns (domino effect).

9 EXAMPLES OF APPLICATION

Case	Type of barrier (minimum requirement)	Section
Equipment validated for O2 use without barrier in a AL plant	None	-
Equipment validated for O2 use without barrier outside AL plant property	Fence	§6; §7.3
Equipment validated for O2 use with barrier and proximity of a critical public zone (i.e. within the Overall Safety Distance)	Walls and partial roof	§6.1; §7.1; §7.1.2.4; §8
Equipment validated for O2 use with barrier inside AL plant and permanent presence of people within the Overall Safety Distance (offices)	Walls and partial roof	§6.1; §7.1;§7.1.2.4; §8
Equipment validated for O2 use with barrier and presence of people within the Overall Safety Distance negligible	Walls Or Jet Safety Distance	§7.1 §7.2; §7.3

Appendix A Overall Safety Distance

Overall Safety Distance (OSD)



P in bar; D in cm; OSD in m

$OSD = 6\sqrt{PD}$

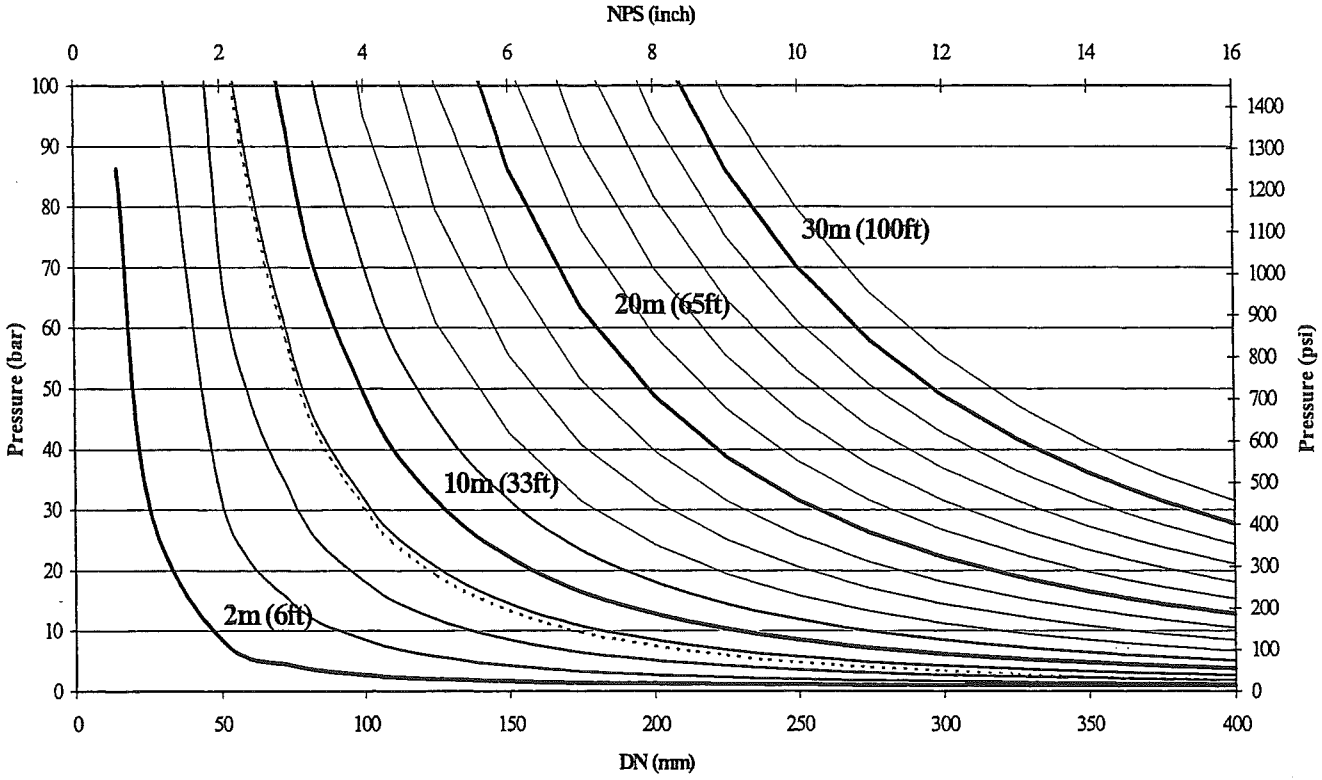
or

P in psig; D in inch, OSD in feet

$OSD = 8\sqrt{PD}$

Appendix B Jet Safety Distances

For a given operating pressure and pipe diameter, the following abacus gives the distance at which the peak overpressure does not exceed 50 mbar in case of pipe rupture. The 50 mbar threshold value has been selected by considering the risk of skull-base fracture. This risk is negligible for an exposure time of less than 20 seconds to this overpressure (see REF7).



Jet Safety Distance:

with D_s in m ; P in bar and D in cm

$$D_s = 0.143 \times \sqrt{1.017 \times PD^2 - 0.81 \times D^2}$$

with D_s in feet; P in psi and D in inch

$$D_s = 0.3131 \times \sqrt{0.997 \times PD^2 - 11.64 \times D^2}$$

In any case, Jet Safety Distance must be at least 2 meters (6 feet).

Appendix C Incidents Data (Projectiles Plotting and Walls Damage)

Table 1 is an extract of the incidents collected in the ETC database, for which information related to projectiles was available. It shows that heavy projectiles have been thrown away at a significant distance even in the case of walled stations.

N°	P (bar)	DN (mm)	Mass of the projectile (kg)	Range (m)
141	**40**	**150**	**15**	**10**
	40	**150**	**5**	**20**
56	**40**	**300**	**10**	**80**
	40	**300**	**5**	**100**
66	**40**	**200**	**8**	**40**
52	**40**	**250**	**5**	**33**
57	**30**	**300**	**1**	**80**

Table 1

Note: the above stations were equipped with walls.

Table 2 is also an extract of the ETC database, for which information related to walls behavior was available. It shows that, in some cases, concrete walls have been partially or totally destroyed by the jet load.

Incident N°	Pressure (bar)	DN	Jet Load (tons)	Effect
56	40	300	35	Severe damage
54	70	200	28	Walls have been destroyed
52	40 ?	250	25 ?	Walls have resisted
27	40	250	25	Civil works engine has jumped
99	28	300	25	Walls have resisted
119	40	200	16	Walls have resisted
172	40	200	16	Walls have resisted
110	20	250	12	Walls have resisted
66	30	200	11.8	Walls have resisted
141	40	150	9	A detached wall has been overturned
91	30	150	7	Walls have resisted (made of breeze-blocks)
26	16	?	?	Cracked bricks
83	18	150	4	Walls have resisted
131	38	100	3.7	Walls have resisted

Table 2

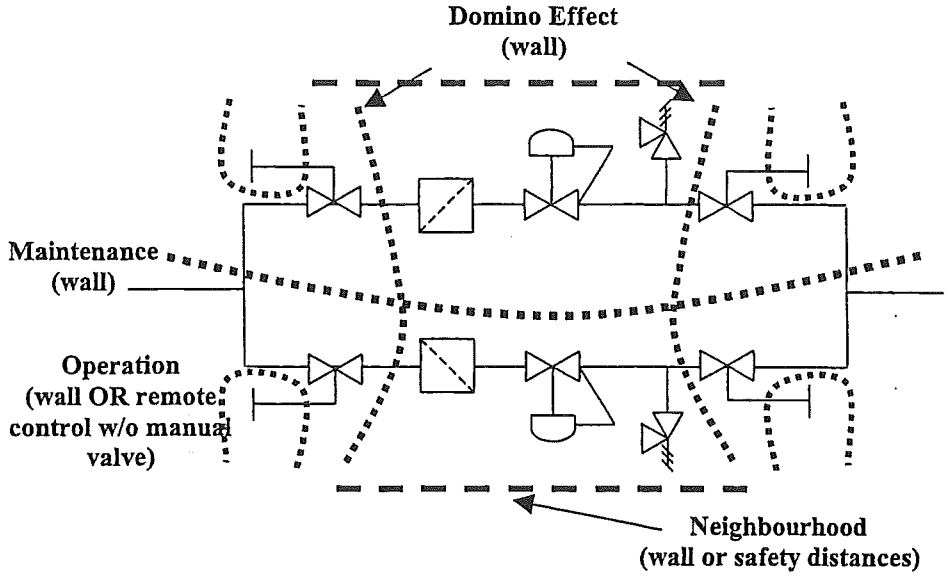
Notes:

Jet load has been calculated by using the formula given in 7.1.1.3.

Except for incident # 141, all the stations were protected by four attached walls (cells).

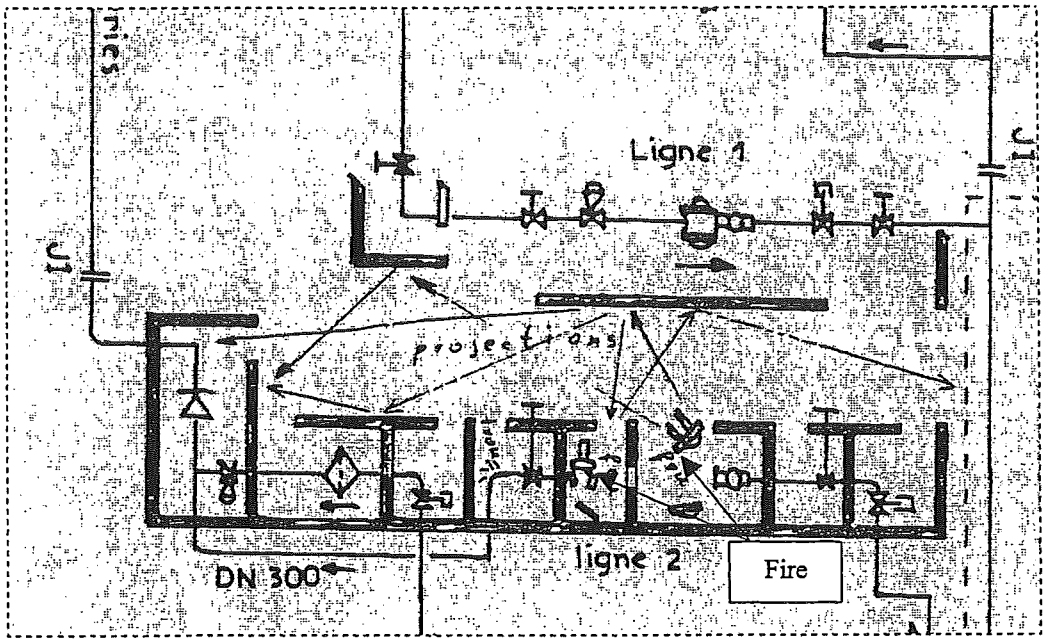
GASEOUS OXYGEN PIPING PROTECTIVE BARRIERS

Appendix D Purpose of the different types of barrier



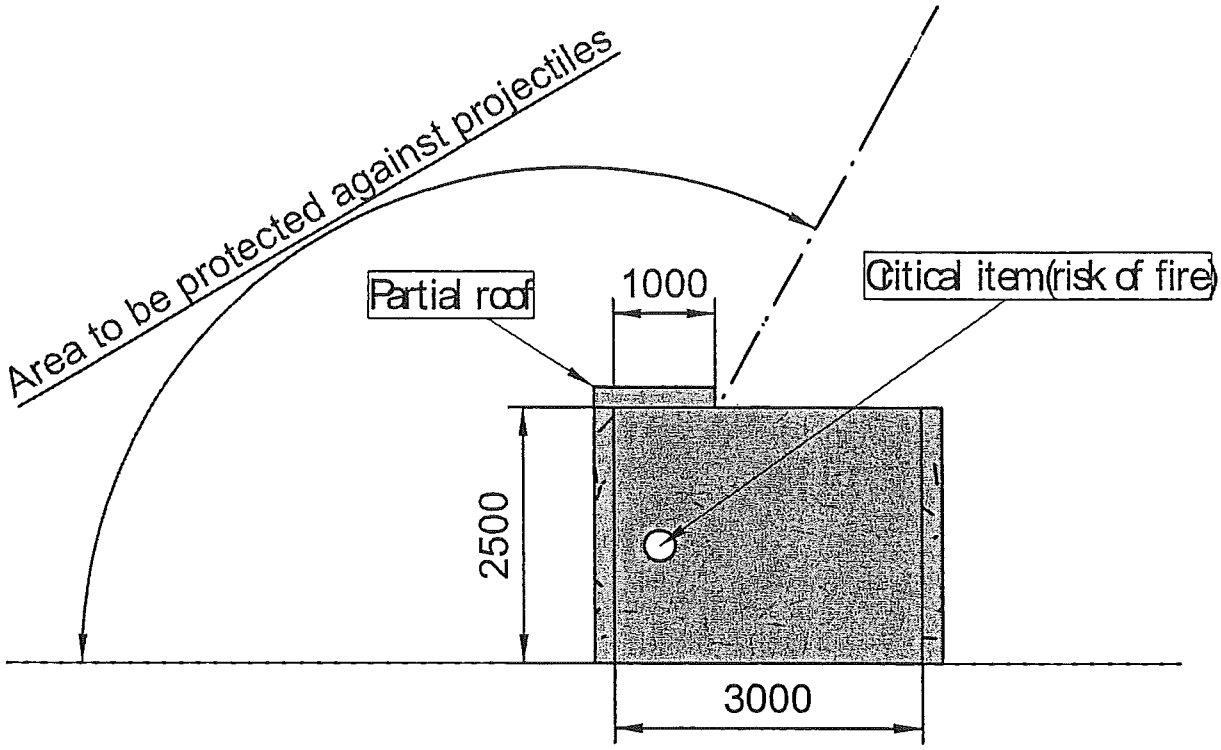
Appendix E Impact Plotting (incident nb 99; extract of the incident report)

This incident shows that some projectiles have ricocheted up to areas considered as safe (**refer to Appendix H for the design of safe labyrinths**).



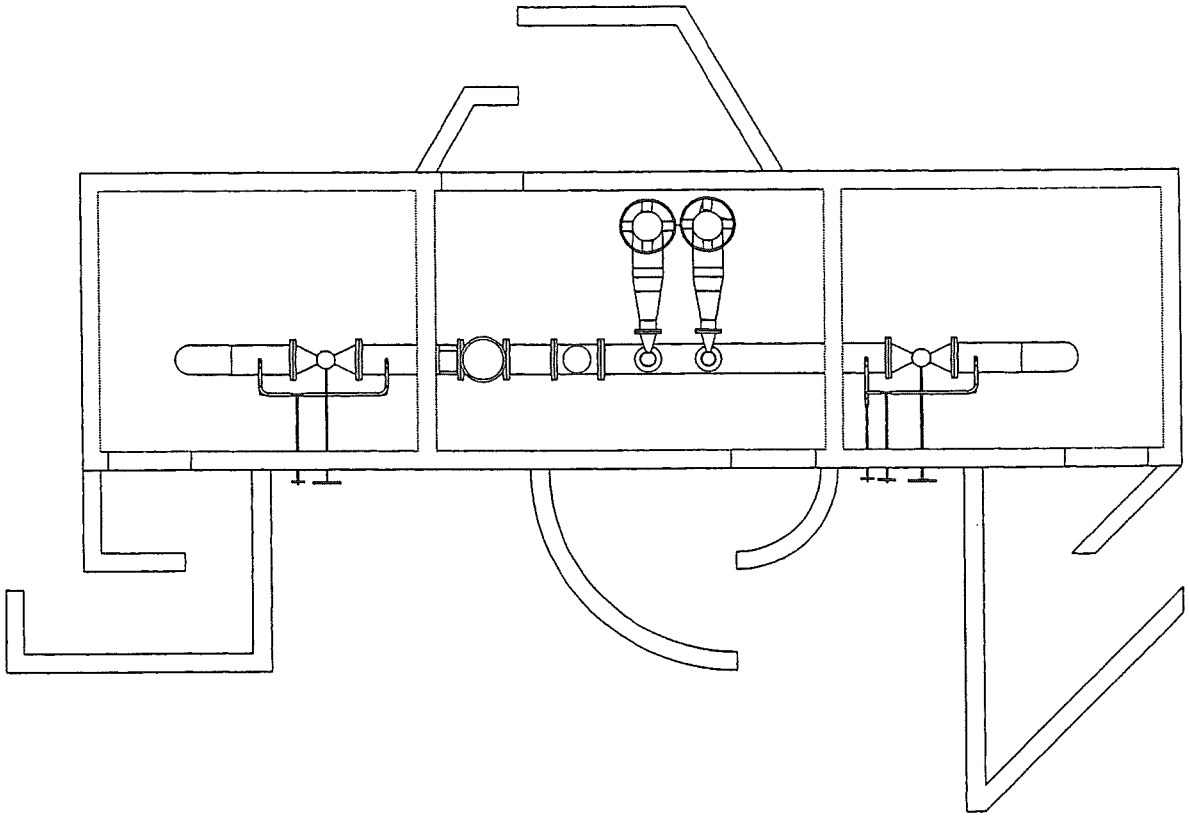
GASEOUS OXYGEN PIPING PROTECTIVE BARRIERS

Appendix F Example of oxygen station with walls and partial roof



Appendix G Various types of labyrinths - Top view

The figure below represents different possible types of labyrinth designed to guarantee that any projectile will rebound at least three times[12] on walls prior to go outside. It shows the complexity of safe labyrinths compared to doors.



[12] Survey of past incidents has shown that many projectiles have rebound two times

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