SEVESO
LIST OF RELEVANT ACCIDENTS AND INCIDENTS

Doc 60.1/25

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Disclaimer

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1 Introduction

The Seveso directive (Annex II 4(c)) requires that the safety report includes a "*review of past accidents and incidents with the same substances and processes used, consideration of lessons learned from these, and explicit reference to specific measures taken to prevent such accidents".* The intent of this appendix is to provide an industry-wide list of example accidents and incidents from which industry lessons can be identified.

For the purpose of this appendix, it is not necessary to attempt to determine retrospectively whether an accident or incident did or did not meet all the elements required for Seveso Major Accident (MA). Even if the accident or incident did not occur on a Seveso site, there is an opportunity to learn.

This Appendix is[1] mainly developed from those gas industry accidents and incidents which have been shared since 1976 within EIGA's Safety Advisory Council (SAC) and its predecessors. Note, most accidents and incidents discussed in SAC focussed on injuries and not all involved loss of containment. Under the confidentiality rules of the EIGA SAC database (see Doc 910, *SAC Data Bank*), the actual causes of any individual accident or incident may not be shared outside of SAC [1]. Only the summaries ("resumes") which are compiled by the EIGA SAC members, may be further shared. It is important to understand that these "resumes" were often written by non-native English speakers. However, the SAC reporting agreement (see Doc 910), requires that the original wording of these resumes is not changed [1].
The overriding intent of reporting these accidents and incidents is for the subsequent SAC discussion and to ensure that relevant EIGA guidance on preventive measures is available. It is important to note that not all accidents and incidents are required to be shared at SAC, so trends or frequency assessment should not be inferred. The number of examples included in each of the following lists is not representative of quantities of accidents or incidents. These examples do not reflect all possible major accident types (see section 9, which describes how to make a comprehensive assessment of scenarios).

	SAC meeting date schedule	
	Year	**Meeting Number**
The 3 digits given identify the SAC meeting at which an accident or incident was reported and so give a broad indication of when it occurred. Many of the early accidents or incidents pre-date industry guidance which is under constant review and development.	1976 - 79	000 to 009
	1980 - 89	010 to 048
	1990 - 99	049 to 084
	2000 - 09	085 to 118
	2010 -2019	119 to 161
	2020 -	162 -

For each collection of accidents and incidents generic "key lessons learned" are given together with reference to relevant EIGA technical guidance.
The selected accidents and incidents were grouped by type of scenario. Where available, accidents and incidents were included to give examples of the range of possible outcomes.
Examples of relevant accidents and incidents are documented for each of the following.

L1. Air Separation facility including storage and tanker loading
L2. Packaged Gases cylinder filling facility
L3. Vacuum jacketed tanks and cryogenic tanker offloading
L4. Hydrogen tube trailers
L5. Acetylene facility

GLOSSARY

[1] Information from one publicly available CSB accident report, as well as the YIMA ASU accident described in [TP63] have been added [2,3]. These events were not in EIGA SAC database.

The resumes often use “company vocabulary” so that different words are used in resumes for the same equipment. A brief glossary of these terms is included here:

Bundle = multiple cylinders connected to common outlet/inlet valves and fixed within a frame = pack
GOX = Gaseous Oxygen
Leads = hoses for pressurised gases
LOC = Loss of containment = release of product
LOX = Liquid Oxygen
MEGC = Multi Element Gas Container = battery vehicle or tube trailer
Pack = multiple cylinders connected to common outlet/inlet valves and fixed within a frame = bundle
Package = cylinder or bundle/pack of cylinders = receptacle
Rack = manifolded collection of fill points to allow filling of multiple cylinders together = ramp
Ramp = manifolded collection of fill points to allow filling of multiple cylinders together = rack
Receptacle = cylinder or bundle/pack of cylinders = package
RPV = Residual Pressure Valve
VIE = Vacuum Insulated Equipment = tank for storage of cryogenic liquids = VJ tank
VJ tank = Vacuum jacketed tank for storage of cryogenic liquids = VIE
Top-filling = addition of fresh gas on top of residual content in returned cylinders, i.e. filling without performing vent/vacuum steps.
Tube trailer = Multi Element Gas Container = MEGC

L.1 Air Separation facility including storage and tanker loading

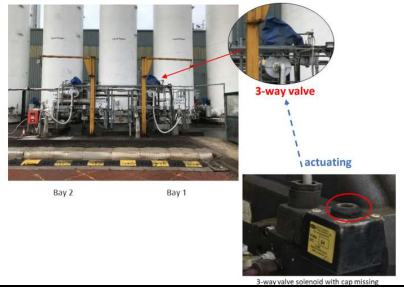
Kind of event that could happen	Example Incidents – Air Separation facility including storage and tanker loading	Key lessons learned	EIGA Doc
COLDBOX If excess hydrocarbons or other contaminants are allowed to accumulate inside cold box components the consequence can be a significant energy release	**118.07.04** A small detonation occurred in the main condenser of the cold box resulting in damage to the column. Weld configuration in some joints resulted in a void space between the outside of the nitrogen pipe and the column head, where it passed through the head. Over time, a crack developed in the upper fillet weld, allowing liquid oxygen to migrate into the void space. This oxygen liquid would be regularly boiled by the relatively warm Nitrogen vapour at the top of the Lower Column and replenished by more Liquid oxygen. Repeating this process would selectively increase the hydrocarbon levels in this void space. **015.06.03** In a main condenser of an air separation unit a small explosion occurred probably by hydrocarbon enrichment. No damages nor injuries. **081.04.04** several detonations in the condenser reboiler caused by ignition of hydrocarbon build-up in the upper column sump resulted in severe internal damage to the column **108.05.06** A major release of LOX from bottom of the LOX adsorber occurred at the recirculating pump area. It is assumed that a hydrocarbon release at neighbouring company caused solid hydrocarbons in an aluminium pipe, which ignited. The purge rate was 1.6% but intermittently low purge rates occurred.	Plant design and safe operating procedures should be in place to prevent dry boiling and/or hydrocarbon build up.	Doc 65 Doc 145 Doc 147 Doc 04 Doc 33 SI-HF 04
AIR PURIFICATION failures Improper control of the front end drying and purifying systems can result in the mixture of hydrocarbons with oxygen. If air or oxygen is introduced into the Molecular sieve beds an exothermic reaction occurs, leading in extreme cases to fire or explosion.	**010.03.01** The plant was restarted after a maintenance period during which a leaking valve on a hydrocarbon absorber had been repaired. The absorber had been on line for an extended period before shutdown due to leakage problem. During plant cool down the absorber was filled with liquid oxygen to test for leakage. The liquid oxygen was then drained into the disposal header. The absorber was then reactivated with nitrogen with the bottom absorber drain left open. Some short time later an explosion occurred in the 10cm dia. Line to the disposal vaporiser. **003.03.06** A fire occurred in a dust filter unit of a molecular sieve battery. The air pressure in the filter was approximately 6 bars and the fire was of sufficient intensity to burn a hole approximately 25cm by 15cm in the filter shell. **087.06.03** A failure in the logical sequence of the air dryers caused the change and gas flow into a just regenerated but not yet cooled dryer. The over 300°C heated air after dryer caused a fire probably in combination with hydrocarbons and oxygen enrichment. Air and a part of the cold box pipeline were destroyed. The cold box was damaged, and perlite released. One person suffered minor first aid injury.	Plant design and safe operating procedures should be in place to control the oxygen concentration and/or overheating in molecular sieves. Procedures for safe maintenance should be implemented, including work permit and vessel opening procedures as well as instructions for re-start after maintenance.	Doc 04 Doc 44 Doc 65 Doc 147

Kind of event that could happen	Example Incidents – Air Separation facility including storage and tanker loading	Key lessons learned	EIGA Doc
DE-OXO SYSTEM De-oxo process involving hydrogen is used to remove oxygen from some crude argon feeds. Under certain conditions Hydrogen can ignite, causing explosion or fire.	**007.03.06** While hydrogen was being transferred from the tube trailer to a static storage installation the valve bonnet of one of the cylinder back isolating valves on the trailer blew out releasing hydrogen at a pressure of approx 200 bars to the atmosphere. The hydrogen ignited and produced a flame of approx 10 metres long. **003.03.03** An internal fire occurred in the crude argon/hydrogen gas feed line to the de-oxo unit. **076.03.04** A contractor employee suffered minor burns when a flammable mixture of hydrogen and air ignited in an absorber vessel during maintenance.	Deoxo and associated hydrogen equipment should be designed and operated as potentially flammable atmosphere areas (ATEX). Procedures for safe maintenance should be implemented, including work permit and vessel opening procedures. Operators should wear specified PPE correctly	Doc 134 Doc 147 Doc 136
CRYOGENIC RELEASES AND VAPOUR CLOUDS Significant release of cryogenic fluids can generate large vapour clouds and can reduce the visibility on and off-site. If liquid oxygen is released the enrichment also increases the likelihood of fire.	**085.05.04** A LOX storage tank, 500 m³ capacity, in an ASU ruptured during normal operation. Severe damage at the tank and escape of liquid, no other damage, no injuries. Cause was overfilling of the tank due to malfunction of the liquid level measuring system. The whole safety feature of the tank has to be improved. **039.01.01** To speed up draining of a LOX HP pump, a worker tried to decrease the set pressure of a small safety valve on the line between tank and pump. He turned the wrong valve; the top part came loose, and LOX was spilled. Loss of 15.000 l. of LOX. **009.01.01** Plant was being shut down, discharge of liquid resulted in a cloud of fog wafting out on a public road. Three cars became involved in collisions, were damaged but nobody was injured. **064.05.01** A cryogenic vapour cloud released from an ASU caused fog on a nearby public road. A car driver disregarded the warning post and collided with another car. No injury. Cars damaged. **026.06.04** Four cars collided on the highway in a dense cloud of fog near an air separation unit after liquid oxygen run over from the total evaporator. Cause of the incident was an Inattention of the operator who did not observe on the lever meter that the vessel was full. Two persons (third party) were slightly injured.	Plant design and safe operating procedures should be in place to reliably prevent overfill. Periodic inspection and maintenance of cryogenic storage vessels should be performed. Emergency plans should recognise when spills or releases inside the plant could have off-site effects.	Doc 04 Doc 127 Doc 233 Doc 224 Doc 190 Doc 147 Doc 200 SI 33

Kind of event that could happen	Example Incidents – Air Separation facility including storage and tanker loading	Key lessons learned	EIGA Doc
	004.03.08 A liquid nitrogen storage vessel ruptured causing secondary damage to a pipeline from a liquid oxygen storage vessel. Liquid oxygen flowed from the pipeline across the facility and on to the property of a chemical company. **006.06.04** At an ASU the liquid oxygen line between the column and a storage tank burst and caused considerable material damage. A nearby street was a time closed by the produced fog. No persons injured. **155.05.01** At an ASU Plant a Flat Bottom LOX Tank failed. A pipeline customer was supplied via the Tank-Pump-Vaporizer back-up system because the ASU was offline for maintenance. An operator heard a loud bang and when he went to investigate he saw perlite and vapour coming out from a rupture at the bottom of the tank. A major loss of containment occurred (approximately 200 t of LOX as the product level in the tank was low). Emergency stops were activated, and the site was evacuated safely. [TP INC 31]		
<u>LOW TEMPERATURE EMBRITTLEMENT</u> Carbon steel equipment items can fail on exposure to cryogenic temperatures.	**044.07.01** At a gas company air separation unit site, on a liquid oxygen LR tank, the bolts holding the bonnet of a liquid gate valve at the foot of the tank broke and, in 12 hours, 700 000 litres of liquid oxygen were spilt. As secondary effect a large crack affected the external carbon steel vessel and there was an emission of perlite. Also, a 1.2 m underground fire water pipe froze and ruptured. The broken bolts were made of carbon steel (should have been stainless bolts with bronze nuts). All cryogenic valves have been checked worldwide to make sure that this will not repeat elsewhere. This should have been checked before start up as required per the pre-start up inspection checklist. **050.07.08** A carbon steel pipeline installed after a steam vaporizer ruptured when an automatic air to open valve failed to close on a signal from the low temperature pipeline protection system. Underground rupture of oxygen pipeline beneath a private road, road damaged, interrupted product supply. Bi-annual check and maintenance of critical safety systems. **028.03.05** Lox was being pumped through a steam vaporizer, the instrument air-line to the steam temperature controller failed, causing the steam valve to close. The low temperature switch at the vaporizer outlet did not activate an alarm or shut down the pump. Cold gas and liquid passed through the vaporizer and into a six-inch pipeline. The carbon steel line ruptured, blowing a hole approx. fifteen feet in diameter and eight feet deep out of the ground. Lox tank retaining wall and the lox transfer line were also damaged.	Design of process equipment to protect carbon steel pipework from exposure to low temperatures. Periodic inspection and test of cold temperature protective (trip) systems should be performed. The required temperature range of all equipment items and components should be understood and specified at design. Proper cold box insulation to prevent cold spots (i.e perlite filling)	Doc 133 Doc 127 Doc 224 Doc 13 Doc 146 TP 60 Doc 200

Kind of event that could happen	Example Incidents – Air Separation facility including storage and tanker loading	Key lessons learned	EIGA Doc
	048.04.02 A section of an oxygen carbon-steel pipeline shattered as oxygen was being fed into the pipeline from a tank pump vaporizer system. Metal fragments were spread over a wide area. No injury. Plant suffered some damage. **053.03.12** During LOX vaporization the LOX pump did not trip out on low outlet temperature from the vaporizer and cryogenic product was introduced into the carbon steel GOX product line. No injury. Small crack in C.S. elbow.		
<u>OXYGEN COMPRESSOR FIRE</u> Problems with compressors in oxygen service can lead to very intense fire/explosion.	**016.04.02** A 72.000 Nm3/h, 37 bar final pressure, oxygen turbo compressor ignited when in normal operation. Fragments from about 30 kg were projected to distances up to 200 m. No injury, damages to LP machine, motor, step-up gear, electric wires, lighting. **042.01.02** A violent oxygen fire broke out in the 3rd stage of the 30 bars GOX compressor probably caused by a small part of the inlet valve disc entering the cylinder and getting stuck between cylinder and piston. The "explosion" caused severe damage to 75-100 m2 of the wall consisting of lightweight steel sheets and windows. 3rd stage of compressor destroyed. No injury. **043.01.01** An explosion occurred due to absence of cooling water followed by a fire which melted the cylinder line and the piston of the 3rd stage of the GOX compressor. Cylinder line and piston destroyed. **060.09.02** After maintenance, a 6 steps oxygen compressor had been coupled to the oxygen pipeline system. A few minutes after the start with oxygen, there was a flash fire in the 6th step of the turbo compressor. Damage to the compressor and gear box. **081.06.02** An oxygen compressor unit and its building were considerably damaged as the discharge line at a two piston oxygen compressor burnt out. Cause was an inadmissible pulsation-frequency of the installation initiated by the pressure-pulsation of the piston compressor. The available equipment to avoid any dangerous pulsation was insufficient designed.	Compressors in oxygen service should be specified, designed and operated correctly. Equipment for use in oxygen should be cleaned. Consideration should be given to enclosing Oxygen compressors within barriers restricting access for personnel protection.	Doc 04 Doc 10 Doc 27 Doc 147 Doc 33
<u>OXYGEN PUMP FIRE</u> Problems with pumps in liquid oxygen service can	**013.00.04** Oil/oxygen explosion in a LOX piston pump. Carrier frame of the cold end destroyed. Piston rod compressed and moved out through the packing box. Cold end bulged inward, and vacuum jacket torn off. Locking device of the gear, guide of oil scraper broken.	Pumps in oxygen service should be specified, designed and operated correctly.	Doc 04 Doc 148

Kind of event that could happen	Example Incidents – Air Separation facility including storage and tanker loading	Key lessons learned	EIGA Doc
lead to very intense fire/explosion.	**072.07.03** Fire occurred in an oxygen cryogenic pump because of an inadequate pump seal material (polyether ether ketone). No injuries, damaged pump.	Equipment for use in oxygen should be cleaned.	Doc 159 Doc 147 Doc 33
GOX BUFFER VESSEL RUPTURE If Gaseous Oxygen Buffer vessels are not properly designed, or are exposed to conditions outside the normal operating envelope, the vessel can rupture or implode	**099.05.01** An oxygen gas buffer vessel imploded due to vacuum in the vessel. The vacuum was caused by wrong design and lacking procedures **107.05.01** A 30 bars, 100 m3 GOX pressure vessel ruptured suddenly causing material damage only. Fatigue cracking starting at a weld imperfection is assumed to be the cause of failure.	Pressure vessels in oxygen service should be specified, designed and operated correctly, recognising fatigue cyclic operation.	Doc 147 Doc 190 SI-HF 04
TANKER FILLING/TOWAWAY After tanker filling, a driver may forget to disconnect the hose before driving away - this can result in a large release of cryogenic liquid (oxygen). Failure of fill process equipment can also result in large release of cryogenic liquid (oxygen).	**127.11.01** After the filling of a road tanker at the Company site, the driver (a contractor) retrieved his truck keys from the control room and started to move, without disconnecting the transfer hose from the filling equipment. The incident caused damage to the filling equipment and to the piping of the tanker. [TP INC 4] **075.04.01** A liquid driver sustained burns to his legs when his trousers caught fire after a heater cable ignited in an analyser house due to an oxygen rich atmosphere. **007.01.05** Tanker was driven away whilst still connected to storage. 3" valve and pipework pulled off tanker and considerable damage to storage tank pipework. Failure to disconnect hose. **058.07.02** A driver fell asleep in the tractor during loading of liquid oxygen at an air separation plant. The plant operator saw the large product release from the pressure relief valve and stopped the pump. Near miss. **104.05.01** The operator should load a LOX rail tank from a LOX storage tank. For reasons unknown he fainted and when the tank was overfilled, the LOX was spilled through the try cock outlet over the operator's body causing a fatal cold injury. The operator did not use the required "dead man's handle".	Written operating instructions should cover normal and abnormal (interrupted) operations Tow-away protection measures should be implemented Drivers should wear specified PPE correctly during filling Plan inspection, calibration and maintenance activities for safety systems (such as Relief valves.) Competent ADR loaders/drivers.	Doc 63 Doc 179 Doc 04 Doc 190 Doc 200 SI-HF 02 SI-HF 04 SI-TS 03 SI-TS 05

Kind of event that could happen	Example Incidents – Air Separation facility including storage and tanker loading	Key lessons learned	EIGA Doc
	167.05.01 In an ASU at one of the truck loading-bays an unintentional release of 39 t of LOX occurred from a storage tank due to a malfunctioning pneumatic valve. It had been affected by cold rainy and stormy weather. Major release of liquid oxygen. No injuries or further damage caused. [TP INC 43] 	Weather protection needs to be regularly checked/maintained.	
CONTROL OF MAINTENANCE/REPAIR /MODIFICATION ACTIVITIES Improperly managed modification or repair to (oxygen) process equipment can result in rupture, energy release or spill.	**057.06.02** At an air separation plant a gas-return-valve of the filling pump of a low-pressure storage tank was repaired but leakage was found during the tightness test. After venting the system when unscrewing the upper part of the valve liquid oxygen splashed. Operator suffered cold burns. Lost time injury. **122.05.04** A worker left a drain valve open when completing a maintenance task on a cryogenic storage vessel. 9 tonnes of liquid oxygen was released, entering the underground sewer system. The sewer was purged with nitrogen. **116.03.01** There was a pressure release and fire from a new section of high pressure oxygen pipeline that was being brought into service as part of an upgrade project that had been installed during the recent ASU3 turnaround. 3 people working in the area at the time were affected by the pressure release, all three were referred to the medical centre with no immediate treatment required and returned to site. Subsequently two of these people have received further treatment, one scaffolder identified with a broken rib, and another Scaffolder with a badly sprained ankle. It was determined that the materials of construction for the control valve and check valve were not suitable. **111.05.01** During maintenance of the actuator of a cold box LOX valve at an ASU Site, the drive shaft was ejected from the valve body. The result was an escape of a considerable quantity of oxygen which resulted in formation of fog with severely reduced visibility. No injuries or environmental impact. The plant was put into emergency shutdown and had to be warmed up to allow examination of the damaged valve.	Leaks from process equipment and other operational issues should be addressed in a timely manner. Planned and unplanned maintenance activities should be controlled using Lockout Tagout (LOTO), Work Permit and – where relevant - Change Management procedures Equipment for use in oxygen should be clean and only suitable lubricants should be used Operators should wear specified PPE correctly	Doc 04 Doc 170 Doc 13 Doc 147 Doc 51 Doc 33 Doc 40 Doc 23 Doc 136 Doc 146 TP 60

Kind of event that could happen	Example Incidents – Air Separation facility including storage and tanker loading	Key lessons learned	EIGA Doc
	144.02.05 Rupture of a buried oxygen pipeline at 40 bar inside the plant at the inlet of the concrete casing under an internal railway due to corrosion along the length of the pipe. Soil, concrete, and water ejected over distances up to 60m from crater of 8m diameter and 3 m depth. Pipe spiral welded built in 1974, coal tar coated and modified in 1991. No injuries, no environmental damage. Material damages. **166.02.01** A worker opened up an oxygen line under 15 bar on the backup system. The line had been isolated but was not depressurised. The work permit was issued for "general works in the area" and didn't specify in detail the works being undertaken. Oxygen release. **026.06.02** After revision a cold box was damaged when a valve of the box burned. Inner parts of the valve were lubricated before with a lubrication unsuitable for liquefied oxygen. Only material damage. **069.05.01** Repair works at an intermediate cooler of an oxygen turbo compressor. Possibility of an oxygen enriched atmosphere was disregarded. Grinding sparks ignited clothing of mechanic, who was fatally burned. **YIMA China 2020 :** A leak in the interconnecting pipe of the coldbox valve in Air Separation Plant C. Process leakage into the perlite insulation. Over pressurization of the coldbox results in a violent blast. Support frame and coldbox plates are cold and brittle. Coldbox collapses smashing into the bulk liquid storage tank and the adjacent Liquid distribution truck's oxygen and fuel oil tanks. Liquid oxygen leaks together with available combustibles (aluminum, etc.) in the area resulting in a violent explosion.15 deaths, 16 seriously injured and 236 hospitalized. [TP63]		
<u>DIESEL SPILL</u> Diesel is classified as hazardous to the aquatic environment. Spills or releases of diesel can contaminate water courses.	**070.04.03** Fuel oil leaked from a broken level gauge line into the bund. A concealed hole in the bund allowed the oil into a drain and finally into a water course. **Doc 113.4.9**: An incident occurred at an industrial gas plant where the diesel fuel was stored in an underground storage tank. The tank was externally corroded and started to leak. The leakage went on for quite some time entailing considerable pollution of the ground.	Environmental protection measures should be implemented including spill management. Periodic inspection of diesel tanks should be considered.	Doc 113 Doc 88 Doc 94 TP 2

Kind of event that could happen	Example Incidents – Air Separation facility including storage and tanker loading	Key lessons learned	EIGA Doc
AMMONIA RELEASE Ammonia is flammable, toxic and classified as hazardous to the aquatic environment. Releases can result in harm to people or the environment.	**076.01.01** The operator tried to stop a leak by adjusting the stuffing-box nut of a valve in the ammonia refrigeration system, but the leak increased. Personnel at the ASU as well as neighbouring companies were evacuated but no injuries. **077.01.04** Two maintenance workers received chemical burn injuries due to poor emptying of the ammonia in the cooling system before repair. **084.01.03** Contracted service men were asked by the plant's personnel to empty oil from the ammonia cooling system in an ASU. When opening the valve, a sudden release of 400 kg ammonia occurred causing neither injuries nor damage. No work permit was issued. **096.02.01** Rupture of a NH3 valve from a refrigeration unit with release of 1 ton of product to atmosphere.	Environmental protection measures should be implemented including spill management Specified PPE should be worn correctly Planned and unplanned maintenance activities should be controlled using Lockout Tagout (LOTO), Work Permit and – where relevant - Change Management procedures.	Doc 40 Doc 147 Doc 136
ANALYSER ROOM – GAS LEAK H_2 RELEASE Small leaks of flammable calibration gases can collect in enclosed spaces, such as an analyser room or cabinet leading to fire or explosion.	**104.02.02** A minor H2 leak took place within the GC leading to explosion of CnHm Gas Chromatograph within the control room of the air separation unit. 	Analytical equipment containing flammable gases should be assessed to prevent risk of potentially flammable atmospheres (ATEX).	Doc 134 Doc 147

L.2 Packaged Gases cylinder filling facility

Kind of event that could happen	Example Incidents – Packaged Gases cylinder filling facility (excluding Acetylene)	Key lessons learned	EIGA Doc
<u>BURNOUT IN OXYGEN FILLING SYSTEMS</u> Many materials will violently burn in a pure or oxygen enriched atmosphere, when an ignition occurs. Such materials include oil, grease and hydrocarbons, but also common construction materials such as plastics, used for valve seats or other sealing elements, and metals such as aluminium, carbon steel and stainless steel. When a small amount of material (e.g. an oil film or a tiny plastic element) ignites inside an oxygen system, the produced heat can rapidly set fire to more material, causing a flash fire. In pressurized systems this often results in an energy release with a potential for serious injury and damage. The most common ignition mechanisms are external heat (friction, welding, flames, etc.), particle impact and adiabatic compression. The risk of ignition increases with increasing pressure and temperature.	<u>Adiabatic compression</u> **011.03.02:** Two cylinder bundles were being charged together with 24 single cylinders on a separate manifold in parallel with the bundle charging system. At 30 bar pressure the bundle charging valve (1) was closed to speed up the charging rate of the single cylinders. When the single cylinders were full, the pump was stopped and the manifold piping depressurised. The operator then opened valve (1) on the pack system. After one turn of the valve there was a loud bang from one of the pack outlet valves, followed by fire which destroyed the flexible connection. **013.05.03:** When opening a master valve in order to direct oxygen from manifold 1 to manifold 2, fire broke out in the ramp. Worker suffered severe burns. 2 master valves, 4 cylinder connection valves and meters of stainless steel pipe were destroyed. **110.13.01:** First burn-out on the filling rack happened because the operator decided to add an extra 10 l cylinder to the filling rack during the filling. When opening the valve, the pressure shock and extreme velocity caused that cylinder valve, connector, hose and a valve on the filling rack to be burned-out. After the fire, the filling system was not cleaned and after filling 3 more batches, the residual particles from the burn-out ignited and caused main valve burn-out. The operator suffered burns and died three days later in hospital. **118.05.02:** During the rack filling of 8 oxygen cylinders the operator identified that one was not filling correctly, the shoulder not being as warm as usual when checked by touch. At the end of the fill he closed the other cylinders off and then started a new fill of the suspect cylinder on its own. An ignition occurred in the cylinder, causing damage to; cylinder neck (burnt through), to the filling rig and a first aid injury to the operator. **121.13.01:** One day before the incident two oxygen 300 bar bundles were filled up to 280 bar. The next day the operator wanted to perform a top-filling to the final pressure. To pressurize the flexible hoses from the bundles he opened the bundle valves. While opening the main valve the adaptor on one bundle ignited. Nobody was injured. Damaged equipment. The cause was probably a pressure shock (adiabatic compression) due to improper work procedure.	Oxygen systems should be designed and operated to avoid adiabatic compression (such as slow-opening valves, inclusion of heat sink into fill hose). Operators who are responsible for oxygen filling, including pre-fill inspections should be competent. Specification of material compatible for use in oxygen service, at the required temperatures and pressures should be defined during design Procedures should be developed to ensure that equipment for Oxygen service is clean. Written operating instructions should cover pre-fill inspections, normal and abnormal operations as well as maintenance. Suppliers of equipment and services should be	Doc 04 Doc 33 Doc 182 Doc 136 Doc 64 Doc 236 Doc 233 SI-HF 05 SI-HF 04 SI-HF 02

Kind of event that could happen	Example Incidents – Packaged Gases cylinder filling facility (excluding Acetylene)	Key lessons learned	EIGA Doc
	143.13.01 During the filling of medical oxygen an oxygen burn out occurred on the intentionally blocked control valve at the automatic HP control valve built into the valve cabinet. [Photo TP INC 20]  **173.11.01:** During the preparation of a specialty mixture cylinder, after the filling of the first component (CO2), the operator started the purging procedure of the line to prepare the filling of the second component (O2). The purging is performed by pressurising and venting the line more than one time. After purging procedure completion, the cylinder valve was opened, scales were tared, and operator started the second component filling by opening the ball valve. Approximately 2 seconds later the ball valve got fire. The operator immediately shut off the main oxygen supply and the flames self-extinguished within few seconds. **170.02.02:** The operator was performing a purge sequence on the oxygen filling ramp, when opening the third cylinder in the sequence, there was a flash fire between the connector and the flexible hose. The operator wore correct PPE including flame retardant clothing, despite this the operator received burns to 35% the body and was hospitalised. **163.14.01:** The operator was filling an oxygen bundle. At the end of the filling process (ca. 190 bar) the operator recognized a leaking noise at the connection between the filling hose and the RPV adapter. He interrupted the filling process by stopping the pump, closing the bundle valve, the filling line valve and relieved the pressure. He tightened the connection between the filling hose and the RPV adapter, restarted the pump and re-opened the filling line valve. An oxygen burnout occurred at the connection between the filling hose and the RPV adapter. A darting flame and/or the filling hose hit the operator in the back (shoulder). The impact was attenuated by protective clothing (fleece & jacket), causing bruise and abrasion and light burn injuries.	subject to quality control procedures. Maintenance personnel working on oxygen systems should be competent. Design of vacuum systems should prevent oil flow into process piping. Flash fire protective Clothing (FFPC) is not certified to protect against oxygen enriched fires, but it may provide some protection. The use of backflow prevention valve can prevent contamination into cylinders. Site emergency plans should outline actions to be taken in the event of fire and product release.	

Kind of event that could happen	Example Incidents – Packaged Gases cylinder filling facility (excluding Acetylene)	Key lessons learned	EIGA Doc
	Material compatibility **021.04.02:** The pressure of oxygen cylinders was checked with a test manometer. The manometer exploded, and the explosion damaged the cylinder valve throwing away the spindle. Operator injured. **104.05.02:** Plastic dip tube was used in high oxygen mixture. Cylinder subsequently exploded whilst being rolled after filling. **132.05.02:** A laboratory technician was analysing an industrial oxygen bundle when an ignition occurred at the regulator - an incorrect regulator had been fitted to the bundle (stainless steel for mixtures service) as the correct regulator was unserviceable. The technician suffered 2nd and 3rd degree burns to 12% of his body (shoulder, elbow, abdomen and left hand), requiring hospital treatment and lost time from work. Contamination **071.06.01:** Two cylinders for medical oxygen connected at a filling rack exploded when opening the vent line before filling. Cause were flammable contaminants by back flow at a customer. One worker was killed, another severely injured, severe damage occurred. **074.04.05:** A carbon steel cylinder ignited and ruptured when the valve was closed at 150 bar at the end of the filling process. Ambient temperature was -36°C and oil was found inside the cylinder. The explosion caused one fatality and one serious burn. **079.06.08:** Grease contaminated cylinder valve and flexible cylinder hose connection from filling station burned out after opening cylinder valve. Employee was seriously injured. Before starting filling, procedure contamination was not noticed by filler. **092.07.02:** At a medical oxygen filling station, an employee was exposed to fire, fumes and cylinder failure when the packaging material of small cylinders stored in a pallet took fire following an explosion in a filling lead. One cylinder in the pallet burst and another flew a few meters. The filling lead explosion was caused by an organic pollution in the cylinder valve following subcontracted maintenance work.		

Kind of event that could happen	Example Incidents – Packaged Gases cylinder filling facility (excluding Acetylene)	Key lessons learned	EIGA Doc
	093.05.02: During filling of medical oxygen there was an explosion in one of the filling ramp valves and the flexible hose damaging the equipment and throwing down cylinders. The vacuum pump oil (oxygen approved up to 2 bars) had been sucked back into the high pressure system due to wrong design of the vacuum pump installation and the cylinders and piping system put under vacuum for a very long time. **157.03.02:** A fire occurred on a 300 bar oxygen filling system. The valve ignited and burned through at the neck thread area causing the cylinder to be ejected from the pallet. It was subsequently propelled upwards landing on a mezzanine platform. Fire service were called and the localised fire was extinguished within 1 hour. **157.02.03:** After completing the filling of 300 bar oxygen cylinder bundles, the employee wanted to depressurize the system. To do this, he opened the corresponding manual valve. The valves on the cylinder bundles were already closed (final filling pressure: 340 bar). When the valve was opened slowly, oxygen burnout occurred in the area of the valve and the downstream pipelines at approximately 320 bar GOX pressure. At that moment, the employee was crouching diagonally to the left in front of the valve. The flash fire burnt the GOX pipe and the flame injured the employee's neck and face as the flash-fire blew the helmet and face-protection mask off his head, the helmet was not fixed. The employee suffered from burned skin grade 1 and 2 on his neck and in his face. He was able to close the valve from the side from a safe position and thus stop the flash fire. [Photo TP INC 33]		

Kind of event that could happen	Example Incidents – Packaged Gases cylinder filling facility (excluding Acetylene)	Key lessons learned	EIGA Doc
	  		

<u>Other</u>

162.02.01 The filling technician bypassed the He/O2 mixture filling procedure, connecting the O2 bundle source directly to the filling panel instead of O2 regulator and using the panel outlet connection as inlet instead. Once he open the O2 bundle valve, the hose that connected the bundle to the panel and another two points (Non-return valve downstream connection and the outlet piping upstream connection) in the filling panel ignited and a fire started in the O2 filling hose. The technician closed the O2 source & start to extinguish the fire using fire extinguishers.

161.13.01: A movable filling rack for filling of small oxygen cylinders was designed for filling of 4 x 6 cylinders. Collector no. 4 was not equipped with filling hoses for a longer time. Operator

Kind of event that could happen	Example Incidents – Packaged Gases cylinder filling facility (excluding Acetylene)	Key lessons learned	EIGA Doc
	cleaned the whole filling rack with water pressure washer. After cleaning, he tried to blow flexible hoses through with the HP oxygen. When he opened the distribution valve to collector 4, the fire occurred in the area of the valve and connected SS hose. **160.11.02:** During the startup of the filling process of a batch of oxygen cylinders, after venting the residual pressure in the line, the operator started the vacuum pump and immediately heard a strong noise due to an ignition and subsequent explosion of the vacuum pump (projection of oil filter cartridges). The operator pushed the emergency stop and extinguished the fire**.**		
OXYGEN PUMP FIRES High pressure reciprocating piston pumps are used to pressurize liquid oxygen prior to vaporizing it for cylinder filling (up to 300 bar). Mechanical failure of bearings or other rotating parts can lead to the generation of friction heat, which can result in the ignition of construction materials that are in contact with the pure oxygen. Contact of oil or grease that is used for lubrication, with oxygen can also lead to fire, or even explosions. Mechanical failures can be generated by normal wear and tear, but also by a pump that runs dry (e.g. due to closed valves, or insufficient cooldown) or by cavitation.	**004.04.05:** A reciprocating pump was left running with the suction valve shut. It caught fire, but the fire went out of its own accord when the pump was switched off. Pump cold end damaged. **014.01.01:** Oxygen-oil explosion at the warm end of the pump. Warm end of the pump completely destroyed, building damaged. **090.05.01:** A liquid oxygen high pressure pump caught fire probably due to a leakage of cold liquid into the crankcase. The crankcase ruptured, and an operator was hit on the finger by a piece of metal. **142.13.01** During filling of two bundles with oxygen at a filling pressure of 307 bar, a fire occurred in the LOX pump. The fire was extensive (flame 6 m high). Nobody was injured. The burn-out took approximately 90 seconds. The fire was extinguished by itself. After that an additional 6 tons of LOX leaked through the ruptured suction line. The cold end of the pump was burnt out, other parts of the pump were also damaged: motor, crank drive, rotary unit and belts. As the suction flexible hose burned out, leaking LOX from the suction side supported the fire and damage of nearby equipment: electrical cable and adjacent electric panel. The most probable scenario for triggering the burn-out of the LOX pump was the failure of the guide ring or the first piston ring following the guide. The ring failed as the pump was exposed to excessive heavy work condition in terms of a combination of:	Design and installation of LOX pumps should avoid risk of cavitation and dry-running, including pump control and consideration of liquid shut off valves Plant design should be based on thorough hazard studies. Specification of lubricants for use in oxygen service, should be defined Written operating instructions should cover maintenance. Preventive maintenance work should be carefully planned and scheduled.	Doc 159 Doc 33 SI-HF 04 SI-HF 05 Doc 236 Doc 04

Kind of event that could happen	Example Incidents – Packaged Gases cylinder filling facility (excluding Acetylene)	Key lessons learned	EIGA Doc
	» not optimal pump-tank installation. The pump was operating, at least partially, below the minimum NPSH [Net Positive Suction Head pressure]. »lack of preventing creation of moisture and/or ice on the piston. »improper operation and pump maintenance. [Photo TP INC 19]  **118.13.05:** During the filling of GOX cylinders the oxygen pump ignited. At the time of ignition, the pressure was 150 bar. A large amount of LOX was released from the LOX storage vessel. Pump was damaged. Nobody was hurt. The analysis showed that the suction filter was broken, and pieces entered the compression cylinder. **144.02.01:** Fire in an oxygen HP pump. The supervisor and other operators extinguished the fire with fire extinguishers. The pump was completely destroyed. Nobody was injured. The seals of the piston and the low-pressure discharge valve were worn beyond the limit causing cavitation. **144.05.02:** After re-start of a LOX-pump a flash-fire occurred followed by a major fire and complete loss of tank content. Major damage to the pump, electrical cabinets, cable-rack and buffer-tank. No personal injuries. Loss of 12 tonnes of LOX.		
<u>CORROSION OF CYLINDERS</u> Internal or external corrosion, or other degradation mechanisms can threaten the integrity of cylinders and can lead to a hazardous energy and/or product release.	**062.06.03:** Due to internal corrosion an oxygen cylinder in a-horizontal bundle had a hole and the gas escaped when the bundle was stored after filling. No other damage occurred. Cause of corrosion: back flow of water at customer's site. **070.01.01:** During filling, an oxygen cylinder burst at a pressure of 124 bar, causing temporary hearing problems for two operators and some material damage, but no serious injury. The cylinder was found to have severe internal corrosion. **077.03.01:** A customer owned cylinder was being filled with a hydrogen mixture when it developed a leak at 4 Bar. The cylinder had developed a crack as a result of H2 embrittlement and was on metallurgical examination found to be unsuitable for use in H2 service.	Thorough periodical internal inspection must be performed. Written operating instructions should address pre-fill inspection. Companies should determine the requirement for Residual	Doc 62 Doc 79 Doc 64 Doc 100 Doc 182 Doc 236

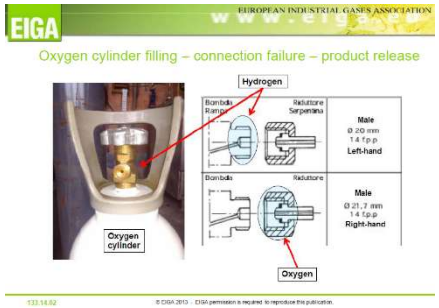
Kind of event that could happen	Example Incidents – Packaged Gases cylinder filling facility (excluding Acetylene)	Key lessons learned	EIGA Doc
	146.14.02: In a SO2 depot a leak occurred, causing the activation of the alarm and sprinkling system. The operators, equipped with self breathing apparatus and chemical resisting clothing, identified the leaking cylinder and moved it to the emergency water basin. After the complete release of the content a hole was found in the base of the cylinder and a brown liquid (lately identified as must was found. Cylinder was destroyed.	pressure valves (RPV) based on product filled and expected cylinder service. Cylinder coating (e.g. paint) should protect against external corrosion. Written procedures should define which cylinder materials are suitable for filling with different gas products. Cylinder and valve Suppliers should be subject to quality control procedures	SI-HF 04 SI 21
MECHANICAL IMPACT FROM FALL Dropping of cylinders, bundles or vessels can result in damage to valves, accessories or piping on those receptacles, resulting in a product release. Depending on the nature of the product, this can lead to further consequences such as fire, explosion or toxic cloud.	**048.06.02:** A driver was unloading with a crane a bundle containing a flammable gas mixture. During the manoeuvring the bundle was caught and fell on the floor. The gas ignited. Lost time injury by burns, bundle and truck damaged by fire. **050.04.03:** During a rearrangement of cylinders on a site a HCL cylinder was dropped and a leak developed. The site had to be evacuated, 12 employees were given hospital treatment. **072.01.02**: During unloading of H2 cylinders in pallets, a pallet on the FLT caught onto a pallet on the truck & fell down head first. Some valves leaked and escaping gas from 2 caught fire. Too long forks, pallets unsuitably designed, valve guards & nuts insufficiently tightened. **080.04.04:** A hand wheel valve on a Silane cylinder was accidentally opened when the cylinder fell. An explosion occurred resulting in the ear drum of the driver being ruptured. **118.05.06:** A 900 litre drum, filled with 475 kg ammonia, was being manually handled during storage operations. The operator allowed the drum to roll against others resulting in an impact	Procedures for replacement of damaged or worn out valve guards should be followed. Cylinder package conformity for ADR ensures they are designed to withstand being dropped without leakage. Forklift trucks should be subject to pre-use inspection and periodic maintenance.	Doc 165 SI 25 SI-HF 02 Doc 52 TB 13 Doc 236 SI-HF 04

Kind of event that could happen	Example Incidents – Packaged Gases cylinder filling facility (excluding Acetylene)	Key lessons learned	EIGA Doc
	on a valve guard. As a result of the impact the guard and valve broke off, resulting in the release of the full contents of the drum. No injuries or environmental impact.	Forklifts should be certified for the load capacity and lifting height. Drivers of forklift trucks should be competent and authorised Proper tools and instructions should be provided for handling of drums. Procedures for ensuring that receptacles are safely loaded, unloaded and secured during transport must be followed.	
MECHANICAL IMPACT FROM VEHICLES Mechanical impact from in-plant or other vehicles can cause damage to valves, accessories or piping on cylinders, bundles, vessels or installations, resulting in a product release. Depending on the nature of the product, this can lead to further consequences such as fire, explosion or toxic cloud.	**116.05.01:** During the unloading of hydrogen cylinder bundles at a customer plant, with a truck mounted crane, an empty bundle came into contact with the pipework on a full bundle, causing damage and a consequent leak that resulted in the uncontrolled release of approximately 250 Nm3 of hydrogen gas and shutdown of the customer's production. The driver had not lowered the sideboard of the truck and therefore had to make a more difficult lift with poor visibility. **116.05.04:** A driver was trying to turn his truck around, after completing the loading with propane cylinders. There was not enough space to make the U-turn, but as he tried, the right front wheel of the truck hit a nearby unprotected hydrogen buffer tank and sheared off a blanked valve. Hydrogen leaked and ignited and streamed into the engine compartment of the truck, leading to further fire and rupture of nominally empty propane cylinders. The driver of the vehicle escaped from the vehicle but was taken by emergency services helicopter to hospital with severe burns.	Fixed installations should be provided with protection against vehicle impact. Drivers of forklift trucks should be competent and authorised A Traffic plan should be in place. Receptacles used to transport products must be certified in accordance with ADR/TPED.	Doc 165 SI 25 Doc 236

Kind of event that could happen	Example Incidents – Packaged Gases cylinder filling facility (excluding Acetylene)	Key lessons learned	EIGA Doc
	126.07.01 The lower piping of a of a vaporiser was ruptured when contacted by a forklift resulting in an 800-liter product leak. After filling the oxygen micro bulk (integrated cryogenic vessel and vaporiser), the forklift approached to move it to the storage area with its forks in the incorrect position above the fork housing. As the vehicle moved forward it broke the lower piping of the vaporiser causing the complete leakage of product. The driver reversed the forklift into a safe position immediately and the area was sprayed with water. Lack of adequate protection against forks striking equipment was detected. [Photo TP INC 3] 		
	161.05.01: When delivering full products and picking up empty cylinders, a customer operated FLT punctured a full oxygen pallet-tank pipe by the forklift forks. The pallet-tank was on the truck-bed when the FLT attempted to unload an empty bundle. [Photo TP INC 37] 		
OVERFILLING OF CYLINDERS When a cylinder, that is filled with a liquefied product, is	**026.03.01:** Ten cylinders (2 litre capacity) had been filled with 2 kg of chlorine. They were put to one side on a pallet awaiting check weighing, 15-30 minutes later one of the cylinders exploded and a second explosion occurred two hours later. The room in which the cylinders	Systems should be designed with measures to avoid overfilling.	Doc 91 Doc 188

Kind of event that could happen	Example Incidents – Packaged Gases cylinder filling facility (excluding Acetylene)	Key lessons learned	EIGA Doc
overfilled, thermal expansion of the liquid can cause rupture of the cylinder, followed by product release. Depending on the nature of the product, this can lead to further consequences such as fire, explosion or toxic cloud.	were standing was filled with fog and it was not possible to enter the room immediately. When it was possible to enter the room only two cylinders out of the ten were damaged. **066.04.01:** A small ammonia cylinder ruptured whilst in storage at a filling station, due to overfilling. This is a near miss incident. Causes include inadequate equipment, inadequate supervision and failure to comply with instructions. **087.05.01:** A 1.5 kg N2O cylinder burst due to overfilling and lack of bursting disk. **175.14.02:** A customer returned an ammonia drum (max capacity 470 kg). Before filling, the drum was checked and found to be overfilled (73 kg above the maximum allowable quantity as per ADR). The cylinder was emptied to the treatment system and sent for scrapping (the overfilling "stretched" and "inflated" the cylindrical part of the drum).	Procedures for verification, calibration and adjustment of critical instruments should be implemented. Written procedures should define overpressure protection requirements for different gas products. Site emergency plans should outline actions to be taken in the event of (toxic) product release.	Doc 236 Doc 233 SI-HF 04
<u>LOSS OF CONTAINMENT (LOC) DURING FILLING OR STORAGE OF CYLINDERS</u> Over pressurising of cylinders or vessels can lead to violent rupture. Often it is the energy release, caused by the sudden expansion of the gas that causes most injury or damage. Depending on the nature of the substance, its release can also cause serious injury or damage. Use of wrong or bad components (e.g. wrong pressure class, incompatible or worn-out connections, damaged parts) can also lead to a LOC during filling.	<u>Overpressure</u> **040.01.04:** The cylinder was connected to the oxygen manifold and the filling started. At about 120 bar the cylinder ruptured. Operator died from his injuries. The cylinder was marked “Chloro” and of low pressure type. The prefill inspection was not done as required **064.05.03:** A flexible hose, not suitable for high pressure, burst during operation with a high pressure oxygen bundle. Similarity of different threads and missing labelling at the flexible tube enabled the mistake. **162.03.01:** There was an unexpected release of Hydrogen due to overpressure of a 200bar Hydrogen filling system that is part of mixed 200bar/300bar filling system. A pressure gauge 'blow out back' opened due to the overpressure resulting in a release of Hydrogen and subsequent detection and alarms. This system was shut down safely with no injuries and minor equipment damage. **CSB2005-05-B [2]** in June 2005 a packaged gas facility in North America was experiencing a heat wave with bright sunlight and temperatures reaching 97°F (36°C). Direct sunlight and radiant heat from asphalt paving heated returned propylene cylinders As the cylinder wall temperatures rose, the internal pressures increased causing the relief device on a cylinder valve to open and vent propylene; the venting propylene ignited (most	Written operating instructions should cover pre-fill inspection. Operators who are responsible for filling, including pre-fill inspections should be competent. Filling systems and procedures should be implemented to minimise risk that cylinders of lower design pressure are connected to wrong manifold.	Doc 78 Doc 91 Doc 100 Doc 236 Doc 233 Doc 80 SI-HF 02 SI-HF 04

Kind of event that could happen	Example Incidents – Packaged Gases cylinder filling facility (excluding Acetylene)	Key lessons learned	EIGA Doc
When cylinders are subjected to extreme heat (e.g. from a fire) the tensile strength of the cylinder material can be affected. This can result in rupture during subsequent filling.	likely from a static discharge) and spread to other propylene, propane and acetylene cylinders. Exploding cylinders flew up to 800 feet, damaging buildings and starting several vehicle fires. CSB found three other similar incidents in North America which occurred in June 1997; August 2003 and July 2005. All of these events occurred in gas repackaging cylinder fill plants on days with air temperatures above 100°F (37°C) and in an area with propylene cylinders <u>Material or connection failure</u> **046.01.04:** During a filling operation, a 20 l. oxygen cylinder burst when the pressure reached 110 bar. The cylinder had been subjected to strong heat, but the burnt valve and valve cap had been changed at the filing station and the cylinder put back into service. No injury. Filling rack, roof of building damaged. **056.03.06:** An operator was filling 49 hydrogen cylinders when one of the pigtail hoses burst. The pressure at the time of failure was approximately 151bar. The shift supervisor, who heard the leak from the admin building, immediately shut down the plant and went to the operator's assistance. Several valves had to be shut off before the leak was isolated. No injury or damage. **061.07.03:** At a specialty gases filling station, on a fluorine cylinder filling rack, a flexible lead "pigtail" was burnt through when starting cylinder filling operation. Minor damages and minor fluorine leak. The flexible leads with internal passivation must be replaced every year.	Written procedures should define overpressure protection requirements for different gas products. Specification of components and materials, including leak detection fluids should be defined during design Modification of plant should be undertaken only in accordance with change management procedures Components that are sensitive to wear should be periodically inspected and replaced. Suppliers of equipment and services should be subject to quality control procedures Cylinders and valves for gases should meet current industry standards Follow industry guidelines for storage of gas cylinders.	

Kind of event that could happen	Example Incidents – Packaged Gases cylinder filling facility (excluding Acetylene)	Key lessons learned	EIGA Doc
	094.03.01: A fire occurred in the SiH4 filling room as a result of a leak suspected to on the cylinder fill rack between the nipple connector and the cylinder valve. The fire caused significant damage to building and equipment. **133.14.02:** During the first filling of a 14 litre customer owned oxygen cylinder, when pressure reached 100 bar, the filling hose suddenly disconnected and whipped, because valve and hose threads did not match. A partial forced connection was possible because the diameter of the valve was slightly less than that of the filling hose. [Photo TP INC 10]  **078.03.02:** A number of cylinder valve failures were traced back to stress cracking caused by repeated application of leak checking fluids containing ammonium ions. **175.11.02** Before proceeding with the filling of a 700kg drum with Ethylene Oxide, the operator carried out the pressure test of the charge connection. As soon as the pressurization with nitrogen was carried out, he detected a leak, stopped the activities, and warned the manager. An in-depth check revealed that both drums returned empty by a customer had the flanges of the quick connections (both gas phase and liquid phase) loosened.	Consider protection from heat in extreme weather situations. Site emergency plans should outline actions to be taken in the event of fire and (toxic) product release.	
<u>TOW AWAY (PULL AWAY) OF CONNECTED RECEPTACLES</u> When bundles, drums or dewars (collectively called "receptacles" per ADR) are moved while still connected to the filling equipment, the filling equipment (pipework or hoses) can break, resulting in a product release. Depending on the nature of the product, this can lead to further consequences such	**111.11.03:** During the activity of transfer from filling area to storage, a worker retrieved with a fork lift a drum of ammonia still connected via a flexible hose to the filling rack, causing the release to the atmosphere. Ammonia was released in a quantity of approximately 50kg, before the on-site emergency team was able to close the valves and stop the leak. Nobody was injured. **120.03.02**: A hydrogen release occurred when a FLT picked up a pack which was in filling process at 120 bar at the time of the incident. The FLT driver was asked by the fill operator to pick up the pack from an adjacent fill manifold. The operator noticed his mistake, stopped his ATEX FLT and pushed the alarm button for a general site evacuation as effect. Approximately 47Kg of Hydrogen were released. There was no ignition. Chains used as anti towaway protection were not in place in front of manifolds in filling process.	Organisational and technical measures to reduce the likelihood of tow away (pull away) should be implemented Drivers of forklift trucks should be competent and authorised Site emergency plans should outline actions to be taken in the event of	SA 36 Doc 165 Doc 236 Doc 233

Kind of event that could happen	Example Incidents – Packaged Gases cylinder filling facility (excluding Acetylene)	Key lessons learned	EIGA Doc
as fire, explosion or toxic cloud.	**121.07.03:** A connected oxygen bundle was towed away after the fill process. The employee was interrupted during the operation and failed to disconnect the fill line before attempting to remove the bundle. Installation was not updated with an automatic tow away prevention system. **166.14.01:** After filling an industrial O2 bundle, the plant operator closed the valves of the filling line and the valve of the bundle. After this operation, a second operator moved the bundle from the filling station with the forklift truck. The filling hose had not been previously disconnected from the bundle, consequently the operator, moving the container, pulled the flexible hose and damaged the filling rack.	fire and (toxic) product release.	
UNCONTROLLED RELEASES DURING CYLINDER RETESTING As part of the periodic retesting process, cylinder valves are removed from cylinders for internal inspection. If this is done on cylinders that were not properly emptied, serious accidents involving fires, explosions or exposure to toxic substances can result.	**040.04.01:** Cylinder test shop operator commenced devalving a cylinder in preparation for hydraulic test. There was a release of H2S gas. Two operators overcome by fumes. **091.05.02:** When internally inspecting an oxygen cylinder, the used lamp ignited a flammable gas or material in the cylinder. The operator suffered burn injuries. **091.05.03:** Two operators were intoxicated by CO while retesting CO cylinders. The CO cylinders were not purged before devalving. **094.02.02:** During the devalving process of an O2 aluminium cylinder probably still under pressure, a violent flash fire occurred destroying the top part of the cylinder and killing the operator.	Procedures should define the venting and purging requirements for different products prior to devalving. Devalving procedures should include check to confirm that the cylinder is depressurised prior to devalving. Operators who are responsible for purging and devalving should be competent. Personnel near to devalving machines shall be adequately protected, for example, using a cage.	Doc 79 SI 18 Doc 23 SI 45 Doc 236 Doc 30 Doc 33 SI-HF 02 SI-HF 04

Kind of event that could happen	Example Incidents – Packaged Gases cylinder filling facility (excluding Acetylene)	Key lessons learned	EIGA Doc
		Devalving machines shall be subjected to a risk assessment.	

L.3 Vacuum jacketed tanks and cryogenic tanker offloading

Kind of event that could happen	Example Incidents – Vacuum Jacketed tanks and cryogenic tankers	Key lessons learned	EIGA Doc
A FLANGE OR CONNECTION LEAK OR RELEASE DURING FILLING If the connections are not made correctly then oxygen can leak, especially as the equipment cools to cryogenic temperatures. This can result in a spray or mist causing cold burns or frost injury to lungs, oxygen enrichment and potential fire hazard.	**136.02.01** After loading LOX, the driver observed a leakage from the outlet valve. He screwed the cap on the loading connection without tightening it, to allow drainage during transport. At the first customer, the leakage on outlet valve got pressure on the cap and when he began to unscrew the cap, it started to leak and produced mist in the cabinet on the trailer. The driver tried to find the emergency stop in the mist with visibility obscured in the cabinet. A splash from the leakage of LOX hit him from the side. The PPE face shield did not protect him enough. When the driver visited the hospital, there was insufficient knowledge about cryogenic burns and no treatment was offered. No lost time accident. Light burns in the cheek. The usual driver told him that the outlet valve had been leaking for a long time, and he had not reported it. **038.04.01** Driver was preparing to transfer liquid oxygen from railcar to road tanker via flexible hose. The hose coupling at the railcar end came undone. Contents were spilled on to the ground. Loss of 50 tons LOX. **140.02.03** A driver of a LOX tanker realised that the level indicator of the tank was not working. When he tried to open the valves of the level indicator, one of the valves became loose, releasing the valve handle and spilling LOX. The driver, wearing cryogenic gloves, tried to reinstall the valve to avoid excess loss of product. The result was 2 burnt fingers on his right hand. **174.11.02:** During the unloading of liquid oxygen from a trailer tanker to storage tank located in the customer´s site, suddenly there was a rapid leak of liquid oxygen from bottom valve of the trailer tanker. The leakage was coming from a broken gasket on the flange of the shutoff valve on the trailer tanker.	Emergency actions by drivers should be defined. Drivers should be trained on the actions to be taken in event of a leak or release. Drivers should wear specified PPE correctly during loading and unloading Equipment issues should be promptly reported and addressed. Provide suitably located Emergency (E-stop) buttons to trip pump and close outlet valve(s).	Doc 23 Doc 136 SI-HF 06 Doc 233 SI-TS 03
PUMP FIRE if cryogenic LOX pumps are not properly operated or maintained then a major fire can result.	**144.05.02** After re-start of a LOX-pump a flash-fire occurred followed by a major fire and complete loss of tank content. Major damage to the pump, electrical cabinets, cable-rack and buffer-tank. No personal injuries. Loss of 12 tonnes of LOX. **030.06.02** During filling liquefied oxygen into a storage vessel at a customer site the pump of a trailer blocked when the impeller touched the labyrinth-sealing. No other equipment was damaged.	Cryogenic pumps should be operated and maintained in accordance with manufacturers' instructions. Drivers should be trained on the actions to be taken	Doc 04 SI-HF 05 Doc 33 Doc 159 SI-HF 02

Kind of event that could happen	Example Incidents – Vacuum Jacketed tanks and cryogenic tankers	Key lessons learned	EIGA Doc
	054.05.02 During transfer of LOX with a centrifugal pump into a stationary tank the transfer pump got warm and ignited causing damage to the pump. The radial clearance of the shaft was too big. **087.05.07** A defect weld in a LOX pump caused a fatigue crack, LOX leakage and an ignition of the pump. The pump manufacturer has informed all customers of this pump type and recommended improvements. **090.05.02** A LOX pump ignited during transfer of LOX due to excessive speed, 7200 rpm instead of allowed 6800. Only pump and transmission damage. **095.04.01** While making a delivery of liquid oxygen the driver noticed a glow in the enclosure for the hydraulic pump drive compartment caused by wear and failure of a rubber seal due to misalignment of the pump drive. Failure of design - location spigot required to assist alignment and failure of management - training of maintenance staff insufficient. **108.05.03** During unloading of LOX at a customer site, the discharge LOX pump caught fire due to lack of lubrication. Pump maintenance was inadequate, and driver was not following procedures. **160.11.03:** After connecting the tank trailer to the customer tank for the delivery of liquid oxygen, the driver pushed the start button of the cryogenic pump of the trailer. Just after pushing the button the electrical cabinet installed in the back cabin of the trailer caught fire. The fuse stopped the electrical supply to the pump. The driver closed all the valves and disconnected the hoses.	in event of pump problems Maintenance personnel working on oxygen systems should be competent Equipment for use in oxygen should be cleaned. Suppliers of equipment and services should be subject to quality control procedures.	SI-HF 05 SI-HF 06 SI-TS 03
<u>OTHER RELEASE DURING FILLING</u> Leaks from or damage to hoses and pipework, for example due to tow-away	**066.05.03** Rupture of a LOX filling hose during interruption of filling of a customer tank. Improper pressure release procedure and malfunction of an excess-pressure valve. Written filling instructions to be amended. **128.03.01** A driver was attempting to deliver LOX to customer tank. The tank was supplied with a 220V power supply station. After several attempts without success, due to the customer overload protection, the customer offered us an independent power supply line at 380 V. By connecting the tanker electrical socket to the independent power supply provided, the earth cable melted and immediately after, the liquid hose (which was connected to the tank with gas passing through it) failed as well.	Written operating instructions should cover normal and abnormal (interrupted) operations Tow-away protection measures should be implemented	SI-HF 04 Doc 04 Doc 63 Doc 224 Doc 13 Doc 190

Kind of event that could happen	Example Incidents – Vacuum Jacketed tanks and cryogenic tankers	Key lessons learned	EIGA Doc
	121.11.01 On the occasion of the filling of a LOX tank in a Hospital, the driver departed without removing the hose. The tank was dragged and rotated and the pipe between the tank valve and the vaporizer was bent. There was no spill or injury. **093.09.01** A driver moved an oxygen transport tank while hose connected to the customer's tank. Anti - towaway out of service. Material damages on hose and piping at transport tank. **074.01.05** During LOX unloading at a customer site a pipe failed, resulting in spillage of LOX. The driver was not wearing regulation safety clothing and received burns on his feet. The pipe failed because the wrong material had been used for the application. **058.05.08** After filling of a customer LOX-tank the filling line burst. The safety valve, which should vent the filling line, did not operate. **168.05.02:** After refilling of a customer tank with LOX, the operator detected a minor leak through the fill valve. The operator tried to close the valve further. In this process, the spindle broke and a bigger liquid release was started. The customer was informed, the area cordoned off and emergency services called.	Drivers should wear specified PPE correctly during filling Material specification should be defined during design Plan inspection, calibration and maintenance activities for safety systems (such as Relief valves and towaway protection) Competent ADR loaders/drivers.	SI-HF 02 SI-HF 05 SI-TS 03 SI-TS 05
<u>OVERPRESSURE OF TANK</u> A variety of internal and external factors can cause the pressure inside the tank to rise eventually resulting in rupture.	**053.03.08** A serious near-miss incident was identified where the blow off disc of a cryogenic storage vessel (outer vessel) had been mechanically secured. An inner vessel leak developed causing the outer vessel to become pressurised and it was only the failure of the O-ring that prevented a catastrophic outer vessel failure. No injury or damage. **072.06.01** A vacuum insulated storage vessel burst at the end of the filling procedure carried out from a road tanker. The driver was killed. Cause: overfilling. **102.05.01** When filling a stationary LOX tank from a LOX trailer, LOX was released through a pressure regulating valve to atmosphere. The regulator was set to 0.7 bar to allow the tank to be filled from the ASU process also. The tank was overfilled but not overpressurised - the safety valves (set pressure 4.5 bar) did not open. No injury or damage. The level gauge was defective and the try cock valve was not used. **073.05.04** A LOX storage tank was severely heated but not destroyed by an external fire. The surrounding of tanks must be kept free from flammable material.	Overpressure and overfill protection systems should be correctly fitted, regularly inspected and maintained Written operating instructions should cover normal and abnormal operations Safety distances should be complied with Personnel should be competent in filling operations.	Doc 151 Doc 224 TB 11 Doc 190 Doc 24 Doc 75 SI-HF 02 SI-HF 04

Kind of event that could happen	Example Incidents – Vacuum Jacketed tanks and cryogenic tankers	Key lessons learned	EIGA Doc
MECHANICAL IMPACT damage to piping or tank can cause loss of containment	**050.04.04** Whilst lifting out a liquid oxygen vaporizing coil for a planned inspection, the mobile crane became unstable and toppled approx. 45° striking a LOX storage tank inlet valve spindle. Storage tank fractured. **133.11.01** Customer Unit- Oxygen supply– Pipework from a liquid vessel at a customer site failed primarily as a result of its burial depth being too shallow and it being regularly passed over by heavy vehicles. This resulted in a pipework break with resultant loss of supply, pressure release at break point, and flash fire at electrical junction box occurred during a driver delivery; a 0.5 metre section of subterranean pipe was consumed in the subsequent oxygen-fed fire. The driver correctly isolated the system, then escaped, but fell as he ran from the incident, resulting in minor injuries. [Photo TP INC 11]  **074.07.04** An oxygen flash occurred when a contract driver was attempting to tighten a hose connection fitting with a hammer on an asphalt surface soaked with liquid oxygen. Driver suffered 2nd degree burns to his face	Lifting operations should be properly planned and managed by competent personnel Design of installations should consider vehicle traffic in the vicinity Asphalt should not be used near liquid oxygen installations Personnel should be competent in filling operations	Doc 224 SI-HF 02 Doc 04 Doc 23
RELEASE FROM LIQUID OUTLET VALVES Liquid outlet valves can leak or fail resulting in release of tank contents	**055.03.06** At a cylinder fill depot a bottom fill valve on one of the vacuum insulated lox tanks suddenly failed in the open position. Fortunately, this tank had been fitted with a back-up shut-off valve, thus enabling a quick change of failed valve to be made. No injury, no damage. **059.01.07** When filling a customer LOX tank from a tanker the retaining nut assembly and the valve stem was ejected. 8,000 litres of LOX were spilled before the quick closure valve was activated. The driver received minor injuries. **069.03.03** The fill line isolation valve bonnet burst during the filling of a tank. The driver was splashed with LOX on his body and sustained second degree burns. Carbon steel bolts were used on the valve in place of stainless steel bolts. **004.03.09** A leak occurred at the screwed bonnet on the bottom 1" fill valve on a standard 50 ton vacuum insulated storage tank which operated normally at a pressure of about 6bar. While attempting to investigate and control the leak the bonnet nut failed, and the valve spindle and	Remotely operated or automated emergency shut off valves should be installed Personnel should be trained on the actions to be taken in event of a leaking valve. Material specification should be defined during design and complied with during maintenance	Doc 04 Doc 13 Doc 159 SI-HF 06 Doc 233

Kind of event that could happen	Example Incidents – Vacuum Jacketed tanks and cryogenic tankers	Key lessons learned	EIGA Doc
	plug became separated from the valve permitting an uncontrolled spillage of liquid oxygen. The plant major emergency procedure was immediately implemented, and the local fire services responded promptly to confine the area affected by the spillage.	Emergency actions should be defined Plan inspection, calibration and maintenance activities	
MAINTENANCE FAILURES Improper start up or maintenance can lead to loss of containment during or after the maintenance work	**010.00.01** After installation of a gas meter between VIE and GOX supply line a leak test was made. When the gas was released into the line system the gas meter exploded. 1 person killed, 3 persons injured, damage to building. **012.03.03** The globe valve in the liquid oxygen line from the tank to the pump had been closed to allow the fitter to change the pump cold end. After disconnecting the pump suction line, the fitter went back to his van where he heard a metallic thud followed by the release of the contents of the tank (approx. 8 to 9 tons) through the open suction line. **042.05.01** LOX was being transferred from a road tanker into a tank. The electric fuse blew, was replaced and the pump started immediately and ran dry. A fire broke out. The driver had closed the valves and left the pump switch on before the electrician started the work. No injury, damage to pump, suction and delivery line and valve cabinet. **130.07.02** A vent valve of an oxygen vessel ejected during maintenance at a customer site. An employee was preparing to change the hand-wheel of the venting valve during the annual inspection of an oxygen vessel. The task is part of the routine maintenance activities since the hand-wheel was worn due to oxidation. The elbow-shaped valve is located in the bottom lower section of the vessel with its projected shade within the collar of the vessel. Product can be released through this venting valve in the gaseous phase. The employee used a hammer to loosen and remove the hand-wheel from its supporting elements by tapping the lower section of the hand-wheel. The entire valve suddenly ejected vertically upwards and hit the bottom of the vessel - the only possible direction of projection. **159.14.02:** Piping from a new oxygen cryogenic vessel to an existing pressure reducer was designed and installed by the customer. During the commissioning the oxygen pressure reducer ignited. The flames were extinguished in a few seconds. The operator, who was in the area, closed the line and stopped the leak of oxygen.	Personnel should be competent in maintenance operations Equipment should be designed to minimise the risk of human failure during maintenance activities Material specification should be defined during design and complied with during maintenance Planned and unplanned maintenance activities should be controlled using Lockout Tagout (LOTO), Work Permit and – where relevant - Change Management procedures	Doc 04 Doc 33 Doc 200 Doc 13 Doc 40 Doc 51 Doc 224 SI-HF 05

L.4 Hydrogen tube trailers

Kind of event that could happen	Example Incidents – Hydrogen (tube trailers and bundles)	Key lessons learned	EIGA Doc
LEAKS FROM HYDROGEN TUBE TRAILERS OR BUNDLES Hydrogen gas – being a very small molecule - leaks very easily, ignites readily and burns with an almost invisible flame.	**007.03.07** Driver drove tube trailer away from hydrogen installation with transfer hose still connected. No release of product or fire occurred. **013.05.04** A worker was checking a filled hydrogen bundle. Some cylinders had slipped, he decided to correct the position with the fork of an electrical forklift truck. The connecting pipe broke, hydrogen escaped and ignited. Worker was burned, forklift destroyed. **013.06.02** Due to hydrogen embrittlement three 200 bar hydrogen cylinders mounted in bundles of two battery vehicles have begun to leak near the concave base end after filling with hydrogen. No other damage occurred. **023.01.02** When the pressure of a hydrogen bundle was reaching 70 bar, a leak was heard. The filling pipe connecting nut broke away and the hydrogen leaking ignited. Operator suffered 3rd degree burns, flexible pipe melted. The flexible copper pipe should have been annealed. **026.06.06** Whilst filling a storage vessel the panel of the hydrogen battery vehicle took fire when hydrogen escaped from a damaged pressure reduction valve and the gas ignited. The panel was damaged, and the operator suffered a lost time injury by burns. **029.01.03** A batch of 120 hydrogen cylinders was being vented on the trailer direct into atmosphere. Gas issuing from one cylinder ignited and this in turn ignited the gas issuing from the other cylinders. Operator suffered burns. **037.01.01:** A full hydrogen trailer [MEGC] was connected with a tractor. The trailer got loose and fell down with the cylinders. This caused the filling pipes of the trailer to rupture and the leaking hydrogen burst into fire. No injury, trailer destroyed.	Written operating instructions should cover normal and abnormal operations Transfilling of hydrogen trailers, bundles and cylinders should only be performed in a dedicated ATEX installation which vents to a safe location Personnel should be competent in filling operations. Specification of materials for use in hydrogen service, including leak detection fluids should be defined during design Drivers of forklift trucks should be competent and authorised. Competent ADR drivers. Drivers should be trained on the actions to be taken in event of a leak or release. Emergency actions should be defined for	Doc 63 Doc 165 Doc 134 Doc 75 Doc 23 Doc 78 Doc 100 Doc 233 SA 36 SI-HF 02 SI-HF 04 SI-TS 03 SI-TS 05

Kind of event that could happen	Example Incidents – Hydrogen (tube trailers and bundles)	Key lessons learned	EIGA Doc
		event of hydrogen releases Anti-towaway protection such as brake interlocks and breakaway couplings should be installed where there is a risk of towaway	

L.5 Acetylene facility

Kind of event that could happen	Example Incidents - Acetylene	Key lessons learned	EIGA Doc
UNCONTROLLED RELEASE OF ACETYLENE DUE TO UNSUITABLE CARBIDE STORAGE ARRANGEMENTS If calcium carbide is exposed to water during storage, acetylene is generated.	**024.01.01** When the carbide charging container was elevated it was wet in its lower part, began to glow and to burn. The container had been placed in a cavity in the ground and water had entered. **013.05.02** Explosion in a closed carbide drum during handling. 1 person badly hurt. **004.01.08** A fire had broken out in a carbide drum. No damage. **076.04.04** Floods resulted in calcium carbide store being submerged in water. 30 drums showed signs of swelling and heat. **089.07.02** A 500 kg calcium carbide container gently burst when handled from the transport truck to the storage area of an acetylene plant. Too high calcium carbide loading temperature at supplier's was suspected to cause this incident. Supplier's packaging procedures have been updated to avoid recurrence. **157.02.02** Two workers were fixing a water leak at the cooling towers of an ASU. The water leak got worse so that some of the water was flowing into the calcium carbide storage area. Calcium carbide can generate an explosive atmosphere in contact with water. The calcium carbide storage area is located adjacent to the dissolved acetylene plant (Flammable plant).	Carbide in storage should be kept dry. Carbide should not be stored in areas where water pools can form. Risk assessment should consider the possibility of flooding. Carbide suppliers should be subject to quality control procedures.	Doc 196 Doc 231 Doc 134
UNCONTROLLED RELEASE OF ACETYLENE DURING CARBIDE CHARGING If calcium carbide is exposed to water during charging, acetylene is generated. If air is present a flammable mixture is formed.	**060.05.02** During lifting of a calcium carbide container by elevator the rope broke. Drop of the container from 1 meter height. **058.04.06** An operator was discharging a carbide container in the hopper when he noticed water pouring in the hopper from a small hole in the top of the container. Potential explosion from acetylene/air mixture formed by the water contamination. **057.05.01** A carbide charging hopper was discharged into the acetylene generator. Acetylene/air mixture in the hopper was ignited and a fire occurred. No injury. slight damage to generator. **005.05.02** Deflagration in generator storage hopper. One operator slightly burned. Broken windows in generator house	Exposure of carbide to atmospheric moisture during the charging process should be minimised. Carbide containers should be purged with nitrogen prior to discharging. The competence of operators to conduct carbide charging activities should be verified.	Doc 196 Doc 231 Doc 237 Doc 134 SI-HF 02

Kind of event that could happen	Example Incidents - Acetylene	Key lessons learned	EIGA Doc
	054.01.01 When a carbide container was being prepared for emptying into the generator hopper an explosion occurred followed by a fire. Operator injured by burns and damage to equipment. **041.01.03** During charging the generator there was a fire in the hopper followed by an explosion in the pipes and the body of the dust extractor. No injury. Rubber collar of the hopper, dust extractor pipe, windows destroyed. **029.04.02** When reloading the carbide hopper of an acetylene generator, carbide jammed between the carbide bin and the hopper. When opening the bin, fire initiated. Operator received burns and suffered broken ribs. **043.05.02** After charging carbide into the generator an ignition followed by an explosion occurred. The nitrogen purging was insufficient. Operator injured. Dust exhaust system damaged. **170.05.01** In the process to connect a carbide cart to the hopper of an acetylene generator with a roof crane, the cart got stuck in the upper position. This left a gap of approximately 40 cm between the outlet of the cart and the inlet of the hopper. In the attempt to bridge the gap, a flexible plastic sheet was wound in several layers to create a makeshift connection. A deflagration occurred in the moment when the handle of the cart outlet was opened.	Carbide containers should be earthed prior to charging generators to prevent static electricity build-up. Lifting devices of carbide containers should be of anti –sparking materials and approved for the load to be lifted. Carbide bin landing position on the generator should prevent sparks.	
<u>CREATION OF FLAMMABLE AIR/ACETYLENE MIXTURE IN THE PLANT</u> Air ingress into the process plant (usually during maintenance) can result in a flammable atmosphere.	**002.05.01** Explosion within an acetylene generator. 3 men injured. Damage of building and machinery. Generator itself withstood the explosion. **026.05.01** An explosion occurred in an acetylene generator, followed by ignition of acetylene escaping. The sludge drain valve leaked allowing ingress of air. No injury, severe damage to generator. **067.01.03** An acetylene generator was being restarted after maintenance work. While emptying the first carbide container, ignition occurred in the carbide hopper (probably reaction of carbide dust with residual air). **070.01.03** Cleaning of acetylene generator (maintenance) through manhole. Explosion. Generator was purged with carbon dioxide for 45 minutes. Cleaning resumed, another	Purging and inerting systems should be well maintained. Operators who are responsible for purging and inerting procedures should be competent and authorised. A system of integrity checking of air ingress points should be established.	Doc 40 Doc 123 Doc 134 Doc 231 Doc 239 Doc 237 SI-HF 02

Kind of event that could happen	Example Incidents - Acetylene	Key lessons learned	EIGA Doc
	explosion occurred. Two operators burnt. Probable cause: unreacted poor-quality carbide insulated by lime. **093.04.05** Maintenance of an acetylene generator involved the use of compressed air to clear the sludge build-up in the process water circulation system. System was not isolated nor purged after cleaning pipes. Air remained in the generators and filling rack pipes. Cylinders were filled with an air/acetylene mixture but were subsequently blown down safely.		SI-HF 04
UNSAFE PRACTICES TO CLEAR GENERATOR BLOCKAGES Generators can become blocked by oversized lumps of carbide, and the subsequent action taken to clear this blockage can cause air ingress into the generator.	**006.04.02** Due to poor quality of carbide, the basket inside the generator stopped rotating. The hydraulic safety valve did not operate. After having stopped carbide feeding and opened the generator 2 explosions occurred. Two people injured. **050.01.06** When the foreman tried to dislodge an obstruction inside the generator, a mixture of acetylene and air exploded. He did not respect established and known procedures and was killed. **040.05.01** The rotary screen of an acetylene generator was blocked. Water was splashed by means of a hose through the manhole without inerting and an explosion took place. Operator killed. **110.03.02** A blockage occurred in the vibrator tube conveying carbide from hopper to generator. During the work to clear the blockage a rubber seal on the vibrator tube failed. Approximately 5 kg of carbide (wet and dry) was ejected with considerable force, ricocheting off plant equipment and a wall going up to 25 metres.	Carbide suppliers should be subject to quality control procedures. Procedures for clearing carbide blockages should be established. Operators who are responsible for clearing carbide blockages should be competent and authorised.	Doc 196 Doc 231 Doc 237 Doc 233 Doc 239 Doc 134 SI-HF 02 SI-HF 04
EXPLOSION IN OR LEAK FROM HIGH PRESSURE PLANT Leaks from the high-pressure part of the plant (i.e. compressors and driers) can ignite to create a jet flame or build up without igniting to create a flammable/explosive atmosphere.	**052.05.02** 15 minutes after restarting of acetylene production, the compressor stopped. Pressure was 25 bar. Operator opened a valve of a water separator. The escaping mixture of water, ice and acetylene ignited. No injury or damage. **058.07.03** In an acetylene plant, several explosions occurred starting in a compressor and destroyed a large part of the plant. Four persons were injured. Equipment deficiency caused the initial explosion and then piping design deficiencies lead to propagation of fire and further explosions. **014.04.02** While the operator was opening the drain valve on a drier vessel, the valve assembly was blown off the stub pipe. Release of acetylene gas into compressing area. No injury.	Acetylene leaks should be resolved promptly to prevent build-up of acetylene in the air. Critical systems such as compressor lubrication should be regularly inspected. Good ventilation is important to ensure that	Doc 123 Doc 134 Doc 231 Doc 241 TB 34

Kind of event that could happen	Example Incidents - Acetylene	Key lessons learned	EIGA Doc
Decomposition or other fire ignition mechanisms can result in significant energy releases.	**080.01.06** The pipeline connection of an acetylene drier came loose, and the gas escaped without ignition. No injuries. **137.13.01** A major explosion occurred in an acetylene plant. The HP drying system was completely destroyed and the compressor was damaged. Safety devices (flame arrestors) protected the downstream equipment. The building where the acetylene production equipment was installed was damaged. The most probable cause of acetylene decomposition in the HP drying battery was: due to improper operating of LP and HP drying system in combination with insufficient plant design the acetylene decomposition occurred in the empty, dirty and corroded HP drying battery.	acetylene leaks can safely disperse. Plant design should be based on thorough hazard studies and best industrial practices. Compressor maximum operating pressure should be adjusted according to the ambient temperature.	
<u>EXPLOSIONS IN THE FILLING SECTION OF THE PLANT</u> Explosions can occur during or after cylinders are filled.	**016.05.02** An explosion occurred in the filling section of the acetylene plant and following a fire some acetylene cylinders exploded causing damage to the building and installations. 22 cylinders exploded, 75 were damaged. **016.05.04** After first filling of acetylene, operator opened the valves for the second filling. Three explosions were heard, and a fire started. No injury. **052.01.02** After filling small acetylene cylinders in a rack, the operator disconnected a filling hose and a fire started. The operator had forgotten to close four cylinder valves before disconnecting. Cylinders and part of the building was damaged. **057.02.05** During a thunderstorm the acetylene plant was struck by lightning causing an explosion of 150 cylinders and the 2 filling rooms. **120.05.01** An explosion occurred with a cylinder at an acetylene filling plant. The operator sustained burns and related injuries, two other nearby operators sustained minor physical injuries. Minor fires were allowed to burn for a number of days, and there was significant disruption to the local community due to the exclusion zone established by the emergency services. **127.02.03** After filling acetylene bundles the operator started to close the valves on the bundle with a pneumatic torque wrench. An explosion occurred at one of the cylinders, followed immediately by another explosion and the rupture of the hose connection to another cylinder.	Do not use pneumatic tools to open/close acetylene valves. Define and respect minimum time between end of fill and starting to close valves. Lightning conduction and earthing systems must be regularly inspected and maintained. Leak check every bundle/cylinder before, during and after filling. Safety devices should be subject to regular planned maintenance. Segregate full cylinders away from empty	Doc 123 Doc 134 Doc 26 Doc 231 Doc 225 SI 42 SI-HF 05

Kind of event that could happen	Example Incidents - Acetylene	Key lessons learned	EIGA Doc
	130.05.02 A single cylinder exploded at the end of the filling cycle resulting in injuries and property damage. **159.03.02** On filling an Acetylene cylinder the first time after retest a leak occurred at the base of the cylinder resulting in a minor release of Acetone**.**	cylinders and the methods of identifying full and empty cylinders should be clear to all operators. Filling tolerances should be well understood by operators and strictly adhered to, to prevent over-filled or over-acetoned cylinders. Emergency systems (such as deluge systems and flashback arrestors) should be installed and maintained to limit the extent and impact of plant emergencies.	
<u>ADIABATIC COMPRESSION OF ACETYLENE IN PIPEWORK</u> Adiabatic compression of acetylene can initiate fire or decomposition because the heat which is not dissipated during the compression raises the temperature of the acetylene.	**014.01.02** An insufficiently filled acetylene cylinder was taken to the filling rack. The pressure was 24 bar. When the ball valve and the cylinder valve were opened an adiabatic compression ignited the air/acetylene in the hose which started a decomposition. The hose was not equipped with check valve at the open end. **038.01.01** An acetylene trailer was checked for leakage. When the main ball valve was operated decomposition started followed by fire. Several cylinders exploded. 6 employees suffered burns. **043.01.03** A decomposition took place in the flexible hose of an acetylene bundle after opening of a ball valve to start the filling process. No injury. **043.05.03** When the acetylene cylinder valve was opened decomposition occurred in the filling line caused by adiabatic compression of some air. No injury or damage. **046.01.05** When an acetylene container was being connected an explosion occurred. It was initiated by an adiabatic compression when the container central valve was opened rapidly	The flow rate should be increased gradually (e.g. by opening valves slowly) when introducing acetylene to prevent adiabatic compression. Downstream pipework should be purged of air before the introduction of acetylene. Flame arrestors and non-return valves should be fitted on cylinder filling flexibles to prevent air	Doc 123 Doc 134 Doc 26 Doc 231

Kind of event that could happen	Example Incidents - Acetylene	Key lessons learned	EIGA Doc
	towards a closed valve at the end of the connecting hose. No injury. Cylinders and cylinder valves damaged. **048.01.03** When discharging an acetylene bundle, an explosion occurred in the discharge hose. Decomposition started in the hose due to adiabatic compression and it spread into the cylinders. No injury. **084.01.05** A decomposition started and spread almost all over the high pressure part of an acetylene plant. The cause was probably air ingress in the hose connecting the cylinder and an adiabatic compression of the air/acetylene mixture.	ingress and spread of any deflagration.	
IGNITION OF ACETONE If acetone (the solvent in which acetylene is dissolved inside cylinders to reduce the risk of decomposition) is released to atmosphere, there is a risk of ignition.	**058.05.03** During pumping acetone into a bucket, an ignition occurred.	Acetone systems and transfill activities should be designed and operated reflecting the ATEX risks of flowing flammable liquid and static electricity build-up.	Doc 123 Doc 134 Doc 225 Doc 231
FAILURE TO ADEQUATELY PURGE THE PLANT PRIOR TO MAINTENANCE Breaking into process equipment or piping without adequately purging can result in an explosion, even if only small amounts of acetylene remain.	**010.05.01** Supervisor and 3 employees were modifying the low pressure acetylene pipeline. This section had been ventilated but had not been purged with nitrogen. A flash occurred igniting the air acetylene mixture. 3 employees injured with burns. **028.01.01** During welding of new pipes between generators and gasholder an explosion occurred. The system was purged but the post-generation of acetylene from the water in the gas holder was not considered. No injury. Upper part of the gasholder destroyed. **094.04.04** During maintenance inside an acetylene gas holder, the residual gas exploded, ignited by welding equipment causing extensive damage to equipment but no injury. The cause was inadequate purge procedures, atmospheric testing and work permits. **035.01.05** An acetylene plant had been shut down for 2 years. Prior to restart, some welding repairs were required to a corroded pipe on the low pressure side of the plant. During welding, a section of about 25 metres exploded. It was believed that the pipe had been purged when the plant was shut down, so it was not thought necessary to purge again.	The safe system of work for maintenance activities should include robust purging and inerting procedures. These should also reflect the probable desorption of acetylene from water in the system. Operators who are responsible for purging and inerting procedures should be competent and authorised. Planned and unplanned maintenance activities on acetylene plant and	Doc 123 Doc 134 Doc 40 Doc 51 Doc 241 Doc 231 SI-HF 02

Kind of event that could happen	Example Incidents - Acetylene	Key lessons learned	EIGA Doc
	147.05.01 After draining water/oil emulsion from acetylene compressors, a decomposition occurred in the waste water/oil collector -pit. Collector pit was damaged, and cover destroyed. Nobody was hurt. [Photo TP INC 24] Photographs show pit before and after event  	pipework should be controlled using Lockout Tagout (LOTO), Work Permit and – where relevant - Change Management procedures	
<u>FORMATION OF ACETYLIDES</u> If acetylene is exposed to copper, silver or mercury, it forms an acetylide compound, which is highly explosive.	**042.05.02** An explosion occurred in the piping between the acetylene compressor and the downstream acetylene dryer. A copper blind plate had been forgotten and caused a reaction to copper acetylide and explosion. No injury. Piping, compressor and dryer damaged. Rooms and technical equipment damaged. **053.05.02** At a customer's premises a pipeline for acetylene was made from copper. No injury or damage but potential danger that acetylene and copper react to copper acetylide, which is a highly explosive substance.	Copper, silver and mercury should be excluded from acetylene plant and customer installation designs. Arrangements should be established during maintenance to prevent copper, silver and mercury being brought onto the acetylene plant.	Doc 123 Doc 212
<u>LIME CONTAMINATION OF ENVIRONMENT</u> Loss of containment of corrosive lime slurry into watercourses can alter their pH, causing harm. Lime spills may also release acetylene and should be investigated.	**066.01.01** An acetylene plant had been closed down because lime tanks were full. The anti-siphoning arrangement was out of action and a manual shut-off valve was left open. Lime siphoned from the tanks and filled the pit. During clean-up, lime was diverted into a storm drain, causing stream pollution. **175.11.01** During normal acetylene production activities, an operator has noticed that there was no flow of lime into bund. He decided to check the generator room where he found a high temperature at the lime section (almost 100 °C). In this time no feed was processed into generator and cooling system was off. The operator tried to reduce the temperature by draining the lime through bypass line as the	Lime tanks should be appropriately sized for all foreseeable circumstances. Procedures should be established for action to be taken in the event of	Doc 123 Doc 109 SI-HF 02

Kind of event that could happen	Example Incidents - Acetylene	Key lessons learned	EIGA Doc
	mechanical draining system seemed to be stuck. After opening the drain valve no flow was observed. That led the operator to conclude that the pipeline is blocked next to outlet line of generator, and he performed improper manipulation by loosening the screw connection on bypass line. This action led lime to drain out and uncontrolled leakage occurred. Lime flooded generator area.	full lime tanks or blockages. Operators who are responsible for process operation or lime storage should be competent and authorised.	
ACETYLENE LIBERATED FROM LIME CAN FORM AN EXPLOSIVE ATMOSPHERE Lime slurry may continue to evolve acetylene at a low rate after it is discharged from the generator and while in the lime pit.	**072.05.01** Explosion inside lime container in an acetylene plant. Acetylene had evaporated from the lime. Material damage. Change of design shall prevent repetition. **086.05.01** In a closed lime pit of an acetylene plant an explosion of acetylene / air mixture happened. Ignition spark was produced by the stirrer. In order to prevent repetition, the design of the lime pit and the stirrer had to be changed.	Lime pits should be well ventilated. Lime pits shall be designed and classified as an ATEX zone. All modifications on acetylene plant and pipework should be controlled using Change Management procedures	Doc 123 Doc 134 Doc 51
UNCONTROLLED RELEASE OF ACETYLENE DURING CYLINDER RETESTING Failure to vent cylinders prior to devalving, or accidental opening of valve prior to venting can result in a release of acetylene and possible fire/explosion.	**006.04.01** An atmospheric explosion occurred followed by a fire, during acetylene cylinder inspection after the cylinder valve had been removed. The operator thought the cylinder was empty. **017.01.02** An explosion occurred to a cylinder placed in a valving machine. Escaping gas ignited. No injury. Cylinder, valving machine, roof of the shop damaged. **024.04.03** When removing an acetylene cylinder valve a lot of gas left the cylinder. When trying to tighten the valve, the valve was catapulted, and an explosion occurred. **040.01.01** After loosening a defective cylinder valve the inspector started to unscrew it by hand and the valve was ejected by gas pressure.	Devalving procedures should be established and adhered to. Cylinder valves should always be left closed when the cylinder is in storage or under maintenance. Defective cylinders are a potential source of leaks and should be stored in designated safe places only.	Doc 123 Doc 134 Doc 05 Doc 79 Doc 80 Doc 136 Doc 231

Kind of event that could happen	Example Incidents - Acetylene	Key lessons learned	EIGA Doc
	038.01.02 An acetylene cylinder was cleaned in a wire brushing machine. The acetylene cylinder valve opened during the brushing and the leaked acetylene ignited causing an explosion. No injury. Minor damages. **066.01.04** An acetylene cylinder was sent for devalving without checking by weighing that it was really empty. After devalving the cylinder, the worker started to remove the filter and a cloud of gas came out. A fire started, and the worker received burns to hand (no protective gloves). **169.02.01** A significant fire broke out at the valve during the devalving of an acetylene cylinder, prior to porous mass inspection. The operator did not check that the cylinder had been emptied or he used a scale that was out of order.	Appropriate PPE for the task should be worn correctly. Venting of acetylene cylinders should only be performed in a dedicated ATEX installation which discharges to a safe location.	
<u>UNSAFE VENTING PRACTICES</u> Acetylene vented from cylinders can form a flammable or explosive atmosphere.	**042.05.04** Six cylinders filled with acetylene had to be emptied because they were blowing off acetone. They were emptied at the loading deck without any connection to a piping system. The instructions were neglected. The escaping acetylene ignited. No injury. Little material damage. **045.05.03** Acetylene cylinders were prepared for testing. After they had been emptied into the gasholder 15 cylinders containing some residual gas were left with open valves. An explosion occurred. No injury. Damage to the roof and windows. **046.01.01** Cylinders were being prepared for inspection and the operator was emptying residual gas from them in the inspection room directly. When handling one cylinder the acetylene cloud exploded and a fire started. Operator suffered severe burns. Wall destroyed. **058.05.01** Acetylene cylinders with opened valves were disconnected from emptying rack. Escaping acetylene ignited. Inadequate training and instruction. **058.06.03** For the periodic inspection, acetylene cylinders were degassed outdoors. After having been brought into the workshop, an explosion occurred resulting in 2 killed workers. **113.05.04** A cco was burnt on the face and arm when he opened an acetylene cylinder for a final vent outdoors to atmosphere, prior to maintenance. Actions were contrary to procedures.	Venting of acetylene cylinders should only be performed in a dedicated ATEX installation which discharges to a safe location. Operators who are responsible for acetylene venting activities should be competent and authorised.	Doc 123 Doc 134 Doc 05 Doc 79 Doc 80 Doc 231 SI-HF 02

Kind of event that could happen	Example Incidents - Acetylene	Key lessons learned	EIGA Doc
	099.05.04 The residual pressure in 64 acetylene cylinders was vented directly into the open air outside the retest shop. The gas cloud ignited injuring the operator. Acetylene gas should be emptied through a burner but during summer time the burner had a low capacity.		
TRAILER TOWAWAY If a trailer is driven away without being fully disconnected from the fill/decant pipework, the damage caused to the installation can result in an uncontrolled release of acetylene.	**086.01.03** An acetylene trailer was driven away while still connected to the piping system. Material damage and major gas release. No ignition.	Anti-towaway protection such as brake interlocks and breakaway couplings should be installed where there is a risk of towaway. Competent ADR drivers.	Doc 123 Doc 134 Doc 63 SI-TS 03 SI-TS 05 Doc 26
UNCONTROLLED RELEASE OF ACETYLENE AS A RESULT OF CYLINDER VALVE SHEAR If cylinders are dropped during loading or unloading operations, the valve could shear, allowing the cylinder contents to escape.	**077.03.02** As a pack of acetylene was being loaded onto a vehicle the forks on the lift truck broke causing the pack to fall to the ground. There was no injury and no damage to the pack. **104.07.03** During loading a truck with acetylene bundle one of the forks of a fork-lift breaks. The bundle was lifted 1 meter.	Forklift trucks should be subject to pre-use inspection and periodic maintenance. Load capacity of forklifts should be confirmed for the load and lifting height. Drivers of forklift trucks should be competent and authorised. Cylinder package conformity for ADR ensures they are designed to withstand being dropped from height of 2m without leakage.	Doc 80 Doc 165 SI-HF 02

Kind of event that could happen	Example Incidents - Acetylene	Key lessons learned	EIGA Doc
ACETYLENE CYLINDER FIRES WHILE IN USE Fires can result if a cylinder or attached equipment leaks.	**019.03.04** The acetylene cylinder caught fire around the valve. It was not possible to close the valve as its plastic handle melted. The fire was brought under control. **075.04.02** A major fire resulted at customer's acetylene distribution system when a leaking connection was ignited by sparks from grinding. The flame impinged on the pipe causing a deflagration. Three cylinders ruptured.	Safe systems of work should be established before allowing hot work such as welding or cutting to commence. Emergency procedures for dealing with acetylene cylinder fires should be established. Flame arrestors and non-return valves should be used on oxy-acetylene welding/cutting equipment.	SI 05 SL 04 Doc 123 Doc 134 Doc 80 Doc 212 Doc 233 Doc 231
FIRE INITIATED BY LIGHTNING Fires can be caused by lightning striking cylinders/bundles.	**024.05.01** A storm was taking place when lightning struck one of the acetylene bundles. The hose connecting the bundle to the piping burnt and the bundle was cracked. Flame arresters prevented the decomposition from spreading to all cylinders.	The need for lightning protection should be considered during risk assessment of cylinder/bundle locations as well as customer installation, acetylene process plant and vent system designs.	Doc 123 Doc 134 Doc 80 Doc 212

Kind of event that could happen	Example Incidents - Acetylene	Key lessons learned	EIGA Doc
MECHANICAL IMPACT FROM VEHICLES Mechanical impact from in-plant or other vehicles can cause damage to valves, accessories or piping on cylinders, bundles, vessels or installations, resulting in a product release.	**157.14.05** A forklift hit an acetylene bundle with the forks, causing a crack and leakage of acetylene and acetone. There was no ignition and no consequences for people/environment [Photo TP INC 33]  	Fixed installations should be provided with protection against vehicle impact. Drivers of forklift trucks should be competent and authorised A Traffic plan should be in place.	Doc 165 SI 21 SI 25 SI-HF 02

2 References

[1] Doc 910, *SAC Data Bank*, *eiga.eu*
[2] CSB accident report, https://www.csb.gov/praxair-flammable-gas-cylinder-fire/
[3] TP 63 - Yima City Gasification Plant Incident, *eiga.eu*

Doc 04 Fire Hazards of Oxygen and Oxygen Enriched Atmospheres
Doc 05 Guidelines for the Management of Waste Acetylene Cylinders
Doc 10 Reciprocating compressors for oxygen service. Code of practice
Doc 13 Oxygen Pipeline and Piping Systems
Doc 23 Safety Training of Employees
Doc 24 Vacuum Insulated Cryogenic Storage Tank Systems Pressure Protection Devices
Doc 26 Permissible Charge / Filling Conditions for Acetylene Cylinders, Bundles, Battery Vehicles
Doc 27 Centrifugal Compressors for Oxygen Service
Doc 30 Disposal of Gases
Doc 33 Cleaning of Equipment for Oxygen Service
Doc 40 Work permit systems
Doc 44 Hazards of Oxygen Deficient Atmospheres
Doc 51 Management of Change
Doc 52 Load Securing of Class 2 Receptacles
Doc 62 Methods to Avoid and Detect Internal Corrosion of Gas Cylinders and Tubes
Doc 63 Prevention of Tow-Away Incidents
Doc 64 Use of Residual Pressure Valves
Doc 65 Safe Operation of Reboilers/Condensers in Air Separation Units
Doc 75 Methodology for Determination of Safety and Separation Distances
Doc 78 Leak Detection Fluids with Gas Cylinder Packages
Doc 79 Cylinder Retest Stations
Doc 80 Handling Gas Container Emergencies
Doc 88 Good Environmental Management Practices for the Industrial Gas Industry
Doc 91 Use of Pressure Relief Devices for Gas Cylinders
Doc 94 Environmental Impacts of Air Separation Units
Doc 100 Hydrogen Cylinders and Transport Vessels

Doc 109	Environmental Impacts of Acetylene Plants
Doc 113	Environmental Impacts of Transportation of Gases
Doc 123	Code of Practice - Acetylene
Doc 127	Bulk Liquid Oxygen, Nitrogen and Argon Storage Systems at Production Sites
Doc 133	Cryogenic Vaporisation Systems - Prevention of Brittle Fracture of Equipment and Piping
Doc 134	Potentially Explosive Atmospheres EU Directive 1999/92/EC
Doc 136	Selection of Personal Protective Equipment
Doc 145	Safe Use of Brazed Aluminium Heat Exchangers for Producing Pressurized Oxygen
Doc 146	Perlite Management
Doc 147	Guideline for Safe Practices Guide for Cryogenic Air Separation Plants
Doc 148	Stationary Electric-Motor-Driven Centrifugal Liquid Oxygen Pumps
Doc 151	Prevention of Excessive Pressure during Filling of Cryogenic Vessels
Doc 159	Reciprocating Cryogenic Pumps and Pump Installations for Oxygen, Argon, and Nitrogen
Doc 165	Safe Operation with Fork Lift Trucks
Doc 170	Safe Design and Operation of Cryogenic Enclosures
Doc 179	Liquid Oxygen Nitrogen and Argon Cryogenic Tanker Loading Systems
Doc 182	Pre-fill Inspection of Customer Owned Cylinders
Doc 188	Safe Transfer of Toxic Liquefied Gases
Doc 190	Plant Integrity Management
Doc 196	Calcium Carbide Specification, Storage and Handling
Doc 200	The Safe Design, Manufacture, Installation, Operation and Maintenance of Valves Used in Liquid Oxygen and Cold Gaseous Oxygen Systems
Doc 212	Acetylene Installations at Customer Sites
Doc 224	Static Vacuum Insulated Cryogenic Vessels Operation and Inspection
Doc 225	Solvents for Acetylene Filling
Doc 231	Response to Operational Issues in Acetylene Plants
Doc 233	Emergency Response Planning
Doc 236	Best Operations Practices for Filling Plants
Doc 237	Safe Operation of Acetylene Generator Systems
Doc 239	Mechanical Integrity of Generator Systems in Acetylene Plants
Doc 241	Purification, Compression and Drying of Acetylene

Doc 257	Safe Blow-down of Acetylene Cylinders and Bundles
SA 36	Tow-Away / Pull-Away Risks
SI 05	Flashback and Flashback Arrestors in Welding Applications
SI 18	Devalving Gas Cylinders
SI 21	Cylinder Valves - Design Considerations
SI 25	Handling of Cylinders Using a Crane
SI 33	Incidents Involving Manually Actuated Isolation Valves in LOX Service
SI 42	Acetylene Cylinder Base Corrosion
SI 45	Risk of Instant Flash Fire during Cylinder Maintenance
SI-HF 02	Individual - "Training and Competence"
SI-HF 04	Task – “Design and Effectiveness of Procedures”
SI-HF 05	Task – “Maintenance Error"
SI-HF 06	Organisation - "Site Emergency Response"
SI-TS 03	Training: Induction and Refresher Training of Drivers, Management and Other Transport Function Personnel
SI-TS 05	Driver Recruitment Process for Bulk and Cylinder Vehicles
SL 04	The safe transport, use and storage of Acetylene cylinders
TB 11	Loss of Vacuum on Vacuum Insulated Cryogenic Storage Tanks Due to Inner Vessel or Internal Piping Leak
TB 13	Safe Design and Use of Cylinder Pallets
TB 34	Acetylene Plant Safe Operating Pressures and Temperatures
TP 2	ASU Plants Environmental Issues
TP 60	Perlite Management (Perlite and Deperliting Operations)

3 Other references

ADR, Agreement concerning the International Carriage of Dangerous Goods by Road, unece.org
CSB, U.S. Chemical Safety and Hazard Investigation board, www.csb.gov
TPED, Transportable Pressure Equipment Directive, eur-lex.europe.eu
Oxygen e-learning- EIGA : European Industrial Gases Association
Hydrogen eLearning - EIGA : European Industrial Gases Association