POTENTIALLY EXPLOSIVE ATMOSPHERE – EU DIRECTIVE 1999/92/EC

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1 Introduction

The EC Directive 1999/92/EC, which defines the minimum requirements to protect the workers from potentially explosive atmospheres (ATEX 137A) came into force some years ago. The transition period ended on 1 July 2003 when new equipment and new work places must comply. The directive must be fully implemented for existing work places before 1 July 2006. This guideline is issued to facilitate and harmonize the interpretation and implementation among the EIGA members of the required risk assessments and specifically classification of areas where explosive atmosphere may occur according to the directive and related standards.
This section explains why the document was written.

2 Scope and purpose

The scope includes handling and storage of flammable gases and liquids where an explosive atmosphere with air under atmospheric conditions might arise at the industrial gases companies' plants. The guide does not apply to the use of flammable medical gases or the risk arising in piping systems, cylinders and vessels with increased pressure.

The classification of hazardous areas according to this guide and EC Directive 1999/92 can also be used for the selection of ex-classified equipment and systems as required by the Directive 94/9/EC concerning equipment and protection systems intended for use in potentially explosives atmospheres (ATEX 100a).

3 Definitions

Explosive atmosphere means a mixture with air, under atmospheric conditions of flammable substances in the form of gases, vapours, mists (or dusts) in which, after ignition has occurred, combustion spreads to the entire unburned mixture.
Explosive limit, lower (LEL) is the concentration of flammable gas or vapour in air, below which the gas atmosphere is not explosive.
Explosive limit, upper (UEL) is the concentration of flammable gas or vapour in air, above which the gas atmosphere is not explosive.
Hazardous area is a place in which an explosive atmosphere may occur in such quantities as to require special precautions to protect the health and safety of the workers.
Ignition temperature is the lowest temperature of a heated surface at which, under specified conditions, the ignition of a flammable substance in the form of a gas or vapour mixture with air will occur.
Temperature class. Equipment is classified by temperature class according to its maximum surface temperature.
Zone 0 is a place in which an explosive atmosphere consisting of a mixture with air of flammable gas, vapour or mist is present continuously or for long periods or frequently.
Zone 1 is a place in which an explosive atmosphere consisting of a mixture with air of flammable gas, vapour or mist is likely to occur in normal operation occasionally.
Zone 2 is a place in which an explosive atmosphere consisting of a mixture with air of flammable gas, vapour or mist is not likely to occur in normal operation but, if it does occur, will persist for a short period only.
Zone 20, 21 and 22 are only valid for dusts and are not defined here.

4 EU Directive 1999/92/EC (ATEX 137A)

The directive specifies the minimum requirements for the protection of workers potentially at risk from explosive atmosphere. It requests the employer to carry out an explosion risk assessment including a classification of the areas and take necessary measures to not endanger the safety and health of workers. It includes organisational measures such as training of workers, work permit system, the need for work instructions, and the use of warning signs as well as the responsibility to coordinate work of employees belonging to different employers. Furthermore, the directive details some specific requirements on the work equipment and work places where explosive atmosphere might arise.

The actions required shall be described in an explosion protection document, (refer to section 6). Workplaces and work equipment placed in service after 1 July 2003 must fully comply with the Directive and this is also valid after modifications and extensions of existing workplaces. For existing workplaces there is a three years transition period before all workplaces must comply.

5 EU Directive 94/9/EC (ATEX 100)

This document is issued in order to harmonize the interpretation of EU Directive 1999/92. However, it is necessary to review the content of the EU Directive 94/9 due to its high importance for work in areas with a risk for explosive atmosphere. The directive 94/9 concerning (mechanical and electrical) equipment and protective systems intended for use in potentially explosive areas is valid when the equipment has an own source of ignition of any kind. It also applies to safety, regulating and controlling devices not placed in explosive atmosphere but forming an integral part of those protective devices. Note that the directive applies **only to new equipment and systems** that are placed on the market after 1 July 2003.

Equipment and devices included in the scope shall

- Bear the CE- as well as Ex proof marking and additional marking according to the directive and be accompanied by a directive conformity declaration.
- Be accompanied at the delivery with comprehensive and detailed instructions (user manual)
- Be classified in Group I or II where group I is intended for use in mines and group II is other applications. Only Group II equipment is in the scope of this document.
- Equipment/devices shall be classified in a category (1, 2 or 3), see below. The category selected will then allow the use of the equipment in the appropriate area where the risk of explosive atmosphere has been defined.
- **Category 1 equipment** must have a very high level of protection even for rare equipment failures and it can be used in zone 0 areas. In the conformity assessment there is a requirement that the manufacturer of the equipment has an approved quality assurance system for the production, inspection and testing, the equipment has passed an EC-type certification and the manufacturer has a notified body to check and verify that the equipment conforms to the EC type certification.
- **Combustion engines and electrical equipment in category 2** can be used in zone 1 areas. The manufacturer must have an approved quality assurance system for the inspection and testing, the equipment has passed an EC-type certification and the manufacturer has checked and verified that the equipment conforms to the EC type certification.
- For **other category 2 equipment**, the manufacturer must provide a technical dossier to the notified body and the production process shall ensure a compliance of the manufactured equipment with the technical documentation.
- For **category 3 equipment**, allowed only in zone 2 areas, the equipment production process must ensure a compliance of the manufactured equipment with the internal technical documentation.
- For all equipment there is also an alternative to send each single equipment to a notified body and have it inspected, tested and categorised.

6 Explosion protection documentation

The explosion protection documentation can be a separate document including all essential information or partly consist of references to previous documentation. Although there is no formal style required, the documentation must be easy to read and understood by all persons concerned and the document must be to date. The directive does not specifically require that the explosion protection document must be a standalone document. To facilitate up-dates and minimize the administrative efforts in the operating company, it is recommended that the explosion protection document refer to other existing documents containing the appropriate information. According to the Directive 1999/92/EC, the Explosion protection document shall demonstrate (Article 8, text copied from the Directive is in *Italic*):

1. *That the explosion risks have been determined and assessed*
2. *That adequate measures will be taken to attain the aims of the Directive* (that is how the minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres are implemented)
3. *Those places which have been classified in zones.*

4. *Those places where the minimum requirements set out apply (*this includes the areas classified in zones as well as equipment in non-hazardous areas which contributes to the safety in hazardous areas)
5. *References to procedures for work permits, training of employees, contractors and visitors and control of work in explosion hazard areas*
6. *That the work place and work equipment, including warning devices, are designed, operated and maintained safely*
7. *That arrangements have been made for the safe use of work equipment as set out in Directive 89/655/EEC concerning the minimum safety and health requirements for the use of work equipment by workers at work*

The explosion protection documentation and related risk assessments shall include not only the normal operations but also maintenance, start up and shut down, cleaning of equipment and plant as well as possible failures and malfunctions. The documentation should include:

- Name of establishment, plant manager, etc.
- Summarized description of the process and number of employees in areas at risk from explosive atmosphere. Process parameters relevant to the risk of explosive atmosphere, for example pressure in equipment with flammable gas, should be stated.
- A list of flammable substances present and its relevant properties, see § 7.3
- As a result of the risk assessment, the areas where a hazardous explosive atmosphere may occur and the classification in zones. Usually it is appropriate to present the result of the zoning on two types of drawing, the layout of the plant and sections of each building .
- The measures (technical and organisational) taken to protect against explosion, arising from the risk assessment
- A list of relevant procedures and work instructions incl. emergency routines
- A list of the electrical and mechanical equipment and their classification for use in hazardous areas. In an annex, manufacturer certificates, EU conformity declarations, risk assessment of existing mechanical equipment and other relevant documents should be filed.

7 Data for the assessment of explosion risks

7.1 General

The risk assessment process should basically consider the likelihood that an explosive atmosphere will occur and the likelihood that ignition sources are present. It shall include normal operations, start and shut down of the process/equipment, check, maintenance and repair activities, cleaning of facilities, common malfunctions and failures as well as foreseenable misuse. The assessment shall also consider the risk of flammable atmosphere spreading to neighbouring areas through openings, ventilation ducts, etc. Equipment, devices and components installed in classified areas before 1 July 2003 do not need to comply with EU Directive 94/9, but a separate risk assessment of the design may be required. It should also be pointed out that all changes of procedures, equipment and facilities in hazardous areas must be risk assessed – the management of change is essential.
Emergency scenarios such as rupture of pipe lines and vessels followed by a release of flammable gases, sudden rupture of a gas cylinder at use, filling or handling and release of the content, etc. should be handled in the sites emergency plans. But these scenarios are not recognized as expected failures or malfunctions and the consequence should not be a base for the risk assessment and classification of hazardous areas according to this guide and the ATEX directives.

7.2 Ignition energy

The energy needed to ignite gases and vapours commonly found in the gas industry can be found below. A general assumption is that ignition of a flammable gas/air mixture requires an ignition source with an energy < 1 mJ and vapour from many solvents needs 0.1 – 3 mJ. The ignition energy mentioned refers to the stochiometric mixture but close to the upper and lower explosion limits the needed energy may be hundred times greater.

The energy needed to ignite a mixture should be compared to the possible energy generated by some common sources such as:

Operating electrical contactor, not ex-proof	many	J
Particles at grinding	some	J
Electrostatically charged person	10-100	mJ
Dropped mobile phone	10-20	mJ

It is very clear that all these sources are fully capable of igniting a gas mixture and the same applies to mobile phones, calculators, PC's and many other electrical devices without any explosion protection. However, the use of ordinary wristwatches and hearing aids in zone 1 and 2 can be allowed due to the fact the possibly generated ignition energy is very low and a very slow gas penetration into the device.

7.3 Properties of involved substances

Physical data of some substances commonly used by the EIGA member companies (ref. EN 60079-10 except for the Minimum ignition energy which is taken from Richtlinien Statischer Elektrizität, 4/1980, BrG Chemie, Germany) Note that the values of the minimum ignition energy in air differs significantly in the literature:

Substance	Density rel. air	LEL in air % vol/vol	UEL in air % vol/vol	Ignition temp. °C	Temp class	Explosion group	Flash point °C	Min. ign. energy in air mJ
Acetylene	0.90	2.3	82.0	305	T2	IIC		0.019
Acetone	2.0	2.5	13.0	535	T1	IIA	<20	1.15
Ammonia	0.59	15.0	33.6	630	T1	IIA		680
Butane	2.05	1.4	9.3	372	T2	IIA		0.25
Carbon Monoxide	0.97	10.9	74.0	605	T1	IIB		
Hydrogen	0.07	4.0	77.0	560	T1	IIC		0.016
Methane	0.55	4.4	17.0	537	T1	IIA		0.21
Propane	1.56	1.7	10.99	470	T1	IIA	-104	0.25

Note 1: Pure acetylene can decompose when exposed to temperature above 350 °C and the decomposition can spread through piping systems at an acetylene pressure of 200 kPa (abs) or more. The contained decomposition causes a large pressure increase. Therefore the UEL for acetylene is sometimes stated as 100%.
Note 2: Some gases not classified as flammable gases such as nitrous oxide, N_2O can decompose at elevated temperature. These gases are not considered in the ATEX directive

The properties above are related to the conditions assumed in the Directive, that is air and atmospheric pressure. At elevated pressure or oxygen enrichment, most of the parameters are significantly changed.

7.4 Ignition sources

The European standard EN 1127-1:1997 identifies thirteen different ignition sources, which are listed below and separated in two groups, one with the ones more relevant for the industrial gases operations and then a group for the remaining sources. The EN standard gives more detailed information concerning protective requirements for equipment in different zones. In general there should be a safety margin between the ignition source and the actual situation when it will be effective. The likelihood of a mal function is also essential for the risk assessment.

Relevant ignition sources
Hot surfaces: An explosive atmosphere can be ignited by a hot surface when the temperature exceeds the ignition temperature of the gas. This might in normal operations be hot pipes, radiators, drying cabinets, brakes and clutches while operated, etc. Malfunctions can generate heat by friction due to loss of lubrication, foreign bodies in moving parts, belts slipping, etc. There shall be a safety margin between the ignition temperature and the surface temperature depending on the zone where the equipment is located.
Flames, hot gases and hot particles: Flames are an inherent ignition source and are present during cutting and welding, and in burners for air heating, etc. Naked flames are never allowed in a classified zone and the enclosure of equipment containing flames must conform to the relevant equipment group/zoning.

Mechanically generated sparks: Hot particles can be generated at grinding or as a result of impact or friction. The ingress of foreign material, for example grit in equipment might be a cause of sparking. Equipment which can produce mechanically generated sparks shall not be used in any zone where a potential explosive atmosphere contains the explosion group IIc substances acetylene, hydrogen, carbon disulphide, hydrogen sulphide or ethylene oxide according to EN 1127-1: 1997, § 6.4.4. However, steel tools which can generate only a single spark such as screw-drivers, spanners, etc. can be used in zone 2 – explosion group IIc substances.
Additional protective measures apply depending on the zone.
Electrical apparatus: Electrical equipment can ignite an explosive atmosphere when, for example closing or opening electrical circuits or by loose connections. The equipment used in classified areas must be certified for the appropriate gas group, temperature classification of the gas and installed and maintained as defined.
Static electricity: Insulated conductive parts and non-conductive materials (solid, liquid or gaseous phase) can be charged to such a high level that the discharge can ignite a flammable atmosphere, see above. The risk is present in most areas and the bonding and earthing of all equipment is essential in all classified zones. Since manual work is carried out in the classfied zones, semi-conductive footwear and floorings as well as appropriate working cloths should be used. Additional precautions apply for non-conductive parts and depend on the calssification of the zone.
Lightning: If lightning strikes, in an explosive atmosphere, it will always be ignited. Furthermore, the lightning can cause currents and sparks at a distance from the actual point of strike. The thunderstorm itself has the potential to create high intensity induced voltages in equipment and systems. If the risk assessment demonstrates a hazard due to lightning, protective measures shall be taken which can include lightning conductors, over-voltage protection as well as bonding and earthing of equipment.
Adiabatic compression: A dangerous adiabatic compression can occur when for example a high-pressure gas suddenly is released into a piping system by a quick opening valve. The gas will be heated up and the high temperature can spread to the external surface of piping and equipment causing a temperature exceeding the ignition temperature of the flammable atmosphere. This shall be avoided in normal operations as well as failure cases as required by the zone classification. Additional hazards are present at adiabatic compression of oxidizing gases. The temperature can be so high that construction materials in the system can be ignited causing an open fire. Furthermore, some gases (acetylene etc.) which are not stable and decompose at temperatures possible to be reached during an adiabatic compression. The decomposition temperature of acetylene cannot be reached in pure acetylene but when the acetylene is mixed with nitrogen or air. The ignition of an air/acetylene mixture requires a lower temperature than to initiate a decomposition. If air is present in part of the system, the air/acetylene might ignite and then it will start a decomposition.
Exothermic reaction: Many chemical reactions are exothermic and can act as an ignition source when the rate of heat generation exceeds the heat loss to the surroundings. Catalysts, for example platinum for oxygen reduction in hydrogen production system, can cause a high temperature. Some combinations of construction material and chemical, for example copper and acetylene can cause reactions which can ignite an explosive atmosphere.
Other ignition sources
Stray electric currents, cathodic corrosion protection: Stray currents can become an ignition source by heating up the current path equipment or by sparks when the stray current is disconnected.
Radio frequency electromagnetic waves: Radio frequency equipment can be used for heating, drying, welding, etc. At powerful fields conductive parts can pick up energy and make connected thin parts (wires) glow or sparks can be generated.
High frequency electromagnetic waves. Electromagnetic waves of high frequency can be absorped by the explosive atmosphere itself or by other materials causing an ignition. Sun light, focused through a lens/bottle can cause high temperatures as well as a laser beam used for distance measurement, fire protection, etc.
Ionizing radiation: Ionizing radiation from X-ray tubes or radioactive materials can act as an ignition source by

a) the radioactive material itself is heated up
b) the radiation is adsorbed and the adsorption material, especially dust particles, is heated up
c) the radiation can cause chemical reactions or decompositions

Ultrasonics: When using ultrasonic equipment, the sound waves can in extreme cases be adsorbed by solid or liquid material resulting in a heat up of the material.

8 Assessment of risk for explosive atmosphere

The first step of the assessment is to make an inventory of, which flammable substances are used, where and for which purpose. At this stage considerations should be given to determine if the flammable substances can be replaced by non-flammable ones. Before such a replacement is carried out the risk of explosion must be considered together with other safety/health/environmental properties as well as technical and economical factors.
The second step is to evaluate if the substance can evaporate/disperse in sufficient quantity to create an explosive atmosphere; this is usually the case for gases. But even if there is an explosive atmosphere present, it might not be regarded as a hazardous (explosive) atmosphere. In reference 12.3 it is stated that less than ten litres of explosive atmosphere, can, depending on local circumstances, be regarded as non hazardous under the condition that the room volume exceeds ten thousand times the volume of explosive atmosphere. When only a non-hazardous explosive atmosphere is present, which can be the case when handling very small quantities of a flammable substance, no further actions are needed.

The last step before the hazardous areas are classified in zones, (see definition), is to prevent by technical measures the occurrence of an explosive atmosphere. One method, scarcely used in the EIGA member operations is the inerting of the atmosphere. Another more common method is to dilute the concentration of the flammable substance in the air by ventilation. In reference 12.4 there is a detailed description how the effects of local and general ventilation can be calculated to arrive at the correct zone classification. With a reliable and efficient ventilation, a room with flammable gas release sources can be classified as non-hazardous. But in the example in this document – an acetylene plant – there are several possible leak sources and rates, why an increased ventilation would not reduce the zone 2 to only a part of the room. Whatever method is chosen, it must ensure that it offers an efficient and reliable protection against an explosive atmosphere. Usually the concentration of flammable substance must be < 25% of LEL (see definitions) under all possible conditions – start up, shut down, operation, maintenance, etc.—before an area can be considered as non hazardous.

When determining the extent of the hazardous zones, the following factors shall be taken into consideration:

- The release type (continuous or intermittent release, accidental release, leakage)
- The release rate, which depends on the geometry of the release source, release velocity, concentration of the flammable substance in the released mixture, and volatility of a flammable liquid

The assessment should cover all operational conditions at the plant such as normal operation, maintenance, commissioning and decommissioning and reasonable malfunctions. It is very important that, operations other than normal are considered. Experience of accidents in the industry involving explosive atmospheres indicates that they normally occur under abnormal operating conditions.

In reference 12.11 a hole of 0.1 mm diameter is used as equivalent release source for leaks from cylinder valves. This includes possible leakage from a valve seat not closed leak tight, leaks from valve gland as well as leak from the joint between valve and cylinder neck. These leakages can persist during normal operation for some period of time until actions are taken by the operators and therefore this defines the extent of the zone 1 area. Bigger leakage will be noticed by the operators and actions will be taken immediately to eliminate the leakage, that is the classification will be zone 2. The leakage rate above can usually also be used for leakage at fixed valves, not welded joints of piping system, etc. to identify the zone 1 areas.
It has been calculated that the 0.1 mm diameter leak hole corresponds to the following leak rates:
Hydrogen, 200 bar = 8.3×10^{-5} kg/sec
Acetylene, 15 bar = 2.3×10^{-5} kg/sec
LPG, 7.5 bar = 1.7×10^{-5} kg/sec
Dispersion calculations show that at a ”worse case” weather, that is very low dispersion, there might be an explosive atmosphere within the following distances from the point of leakage:
Hydrogen, 0.7 m and a narrow jet
Acetylen, 0.1 m and a narrow jet
LPG, 0.05 m
Note also the comment above stating that an explosive atmosphere volume of < 10 litres can be regarded as a non hazardous explosive atmosphere.

Appendices 2 and 3 show examples of the area classification of two typical industrial gas operations, an acetylene plant and a storage of gas cylinders. Note that the actual area classification consists of the column “Area and activity”, “Zone” and “Release mechanism” while the other columns include ignition risk, comments, etc.

Other common EIGA member operations where a flammable atmosphere might be present are:

- Hydrogen plants including filling of high pressure or liquefied hydrogen
- Specialty gas plants handling flammable gases
- Laboratory analysing flammable gases or gas mixtures
- Sites filling propane
- Sites filling industrial or medical gas mixtures containing flammable components.
- CO plants including any filling activity
- Customer stations for acetylene, hydrogen, etc. for cylinder manifold systems
- Customer stations for bulk gaseous or liquid hydrogen

9 Assessment of risk for ignition of hazardous explosive atmosphere

In the classified areas protective measures must be taken to avoid the ignition of potentially flammable atmospheres. These measures depend on the potential for an explosive atmosphere as defined in the zones below, and must comply with the relevant rules:

Zone	Ignition sources (see §7.4) shall be avoided:
Zone 0	In normal operation, in foreseeable cases of malfunctions and in rare malfunctions
Zone 1	In normal operation and in foreseeable cases of malfunctions
Zone 2	In normal operation

The measures to prevent an ignition can be of technical or organisational nature. In the example, appendix 2 and 3, the risk assessment is based on the following general precautionary measures. Note that these are only examples and each operational unit must list the appropriate ones at the relevant site:

Organisational:

- The workers (including any contracted worker) are properly trained in the risks from explosive atmosphere. The company keeps records of training.
- Visitors in areas with risk of explosive hazardous atmosphere shall always be accompanied by an employee. The person responsible for the visitor shall also ensure that the visitors conform to appropriate safety and emergency procedures.
- It is not permitted to bring portable electrical equipment, such as mobile phones, calculators, cameras, etc. into ex-hazardous areas. Electrical wristwatches and hearing aids are permitted.
- There is a work permit system implemented for all non-standard work (repair, maintenance, etc.) and all work carried out by contractors in the classified hazardous area. This includes when an un-certified equipment must be brought into an ex-hazardous area.
- Work instructions are issued and implemented which includes maintenance, purging operations and cleaning
- Emergency instructions are issued and implemented that includes correct behaviour in the event of fire, gas releases, spill of dangerous material, etc. The emergency routines shall be practiced annually

Technical:

- All electrical equipment used in classified areas is appropriately certified for the actual zone according to EU Directive 94/9 or previous international or national standards. This applies also to mechanical equipment such as fans, compressors, turbines, pumps, valve actuators, flame arrestors, etc. put on the market after 1 July 2003
- Ex-labels/signs are in place at the entrances to hazardous classified areas.
- Only spark free tools are available and used in hazardous classified areas, zone 1 and 2. If other tools are to be used a written work permit is required.

- The fixed equipment in hazardous classified areas is electrically bonded to each other and the earth. The efficiency of this bonding should be periodically checked in accordance with national standards.
- All workers at the site must wear working clothes made of material, which will not create electrostatic sparks.
- All workers at the site must wear semi-conductive shoes and the floor shall have semi-conductive properties. Concrete floors have usually semi-conductive properties but a surface treatment of the floor can destroy the conductivity.

In the example of a risk assessment you can find additional precautionary measures related to certain identified risk.
The above mentioned technical and organisational measures will also make it highly unlikely that any person by mistake will bring a potential ignition source into an area classified as hazardous explosive atmosphere.

10 Assessment of risk for ignition of hazardous explosive atmosphere - mechanical equipment in use before 1 July 2003

Equipment placed on the market after 1 July 2003 must fulfil the Directive 94/9/EC as stated in § 5. For older equipment it must be demonstrated before 1 July 2006 that the equipment is designed, constructed, assembled, operated and maintained to minimize the risk of an explosion and this risk assessment should be a part of the explosion protection document. An example of such risk assessment for an acetylene compressor can be found in appendix 1.

An example of mechanical equipment frequently used in classified areas is the forklift truck. Self propelled industrial trucks as well as pedestrian controlled ones can be used in hazardous areas classified as zone 1 or zone 2 under the condition they conform to the EN 1755:2000. EN 1755 is issued to complete the requirements of the Machinery directive and related EN standards when a truck is used in hazardous classified areas where an explosive atmosphere might be present. For forklift trucks not complying with the EN standard, the operator must demonstrate that it is safe to use, this requirement may demand significant resources. An alternative which allows the use of the forklift truck in areas classified as zone 2 is to equip the truck with a flammable atmosphere warning system giving warning long before any dangerous concentration of flammable gas is reached. It is recommended to set the alarm at < 25% of the LEL. The driver must also be instructed to stop the truck when the alarm is activated. The gas alarm is an essential element for the safe operation of the plant and shall comply with the requirements of Directive 94/9/EC, which ensures its suitability for the intended use.

11 Mitigation measures of an explosion

The preferred methods to protect workers potentially at risk from explosive atmosphere are to reduce the risk of having a hazardous explosive atmosphere and an ignition source to an acceptably low level. However, there may be cases when the risk of an explosion is not negligible and mitigation measures must be taken. These measures can include:

- The construction of vessels, pipes and other equipment so they can withstand an explosion without rupturing. In most cases with air/flammable gas the explosion overpressure is not exceeding 10 times the original pressure but exceptionally even higher pressure increases can occur
- The design of equipment or buildings to release the explosion pressure in a safe direction (pressure relief devices). The devices must be carefully designed to ensure its proper functioning and shall comply with the Directive 94/9/EC. A common industrial practice at acetylene plants is to have a pressure release area equal to 10% of the volume of the protected room. Additionally, the roof of acetylene plants can be designed with a weight of < 100 kg/m2. Note that explosion of for example an air/hydrogen atmosphere in a room will result in an extremely fast pressure increase, which will considerably reduce the mitigation effects of pressure relief windows or light walls.
- Prevention of explosion propagation. A commonly used device in the acetylene plants' piping systems is the flame arrester.

Additional mitigation measures exist but since they are of less relevance for the gas industry they are not commented on here. Furthermore, the more traditional fire fighting measures will reduce the

consequences of the fire that commonly will follow after an explosion. These methods include the construction of the building, the availability of emergency exits, fixed and mobile fire fighting equipment, etc.

12 References

12.1 EU Directive 1999/92 on the minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres

12.2 EU Directive 94/9 concerning equipment and protective systems intended for use in potentially explosive atmospheres

12.3 EU's ATEX web site contains the two guidelines below and other relevant information.
- EU guide "Non-binding guide of good practice for implementing Directive 1999/92 (http://www.europa.eu.int/comm/employment_social/health_safety/legislation_en.htm)
- EU guide "Non-binding guide of good practice for implementing Directive 94/9 (http://europa.eu.int/comm/enterprise/atex/guide.htm)

12.4 EN 60079-10, Electrical apparatus for explosive gas atmospheres. Part 10: Classification of hazardous areas

12.5 EN 1127-1, Explosive atmospheres – explosion prevention and protection – Part 1: Basic concepts and methodology

12.6 EN 13463-1, Non-electrical equipment for potentially explosive atmospheres – Part 1: Basic methods and requirements

12.7 PrEN 1839, Determination of explosion limits of gases, vapours and their mixtures

12.8 PrEN 13673-2, Determination of maximum explosion pressure and maximum explosion pressure rise of gases and vapours – Part 2: Determination of the maximum explosion pressure rise

12.9 PrEN 13980 Potentially explosive atmospheres – Application of quality systems

12.10 TR 50404, Electrostatics – Code of practice for the avoidance of hazards due to static electricity, CENELEC, 2003.

Appendix 1: Risk assessment of an acetylene compressor

Below is an example of an assessment of the risk that an acetylene compressor ignites an explosive atmosphere in the room where the compressor is situated. The assessment must be made before 1 July 2006 by the operating company for equipment in use before 1 July 2003. It should be referred to in the explosion protection document.

Assumptions: The compressor is installed in the high pressure building of the acetylene plant where acetylene cylinders are filled. The electric motor is located in a separate room which is not an ex-classified room and the axle between motor and belt pulley is going through the wall and is gas tight sealed. The compressor is belt driven. All safety valves at the compressor are piped above roof at a safe place. The outlet pressure of the compressor is 25 bar. It is water cooled.

Appendix 2: Risk assessment of acetylene compressor in use before 1 July 2003

Item	Detail and /or activity	Failure cases with a possibility to ignite an explosive atmosphere	Comments, precautions etc.
1	Gas tight lead through to electric motor room	Leakage around the axis	The condition of the lead through is checked semi-annually. The lead through is between zone 2 area and a non-classified area.
2	Belt drive	Static electricity due to belt and wheels	The belt is anti-static according to manufacturer specification and it's located in a zone 2 area. Ref. 12.12 states that belt drives should be avoided in zone1 areas for group II gases (acetylene etc.) but can be used in zone 2
3	Belt creeps	Wrong belt tension or compressor failure can cause creeping generating a high temperature.	The belt drive is located in zone 2. Trained operators are present in the room most of the time and will act at suspected malfunctions
4	Lack of cooling water	The cooling water leaks out on the floor	The compressor area is staffed and operators will take actions. The lack of cooling will trip the compressor
5	Seized piston or bearing	Loose parts in the cylinder, failed bearing, etc. can generate considerable heat inside the compressor. The heat will not spread to the external surface but can initiate a decomposition of the acetylene.	The decomposition will be stopped by the flame arrester at the outlet of the compressor. It will not go backwards since the inlet pressure is only 0.1 bar. The safety valves will open and release the pressure to the atmosphere above the roof
6	Lack of lubrication oil	Sudden leakage in oil system or failed oil pump. Oil pressure gauge and oil level sight glass shall be checked daily. No alarm. Absence of lubrication can cause a seizing of the bearing in turn causing a very high temperature. The high temperature can initiate a decomposition or heat up external bearing surfaces to a temperature exceeding 80% of acetylene's ignition temperature.	1. The decomposition will be stopped by the flame arrester at the outlet of the compressor. It will not go backwards since the inlet pressure is only 0.1 bar. The safety valves will open and release the pressure 2. The outer part of a bearing will be heated up for a short while. The event is very unlikely – no failure of this type has occurred during many thousands of compressor years.
7	Ignition of air/acetylene mixture in compressor	1. Start of compressor with air in the system 2. Leakage of air at compressor inlet	1. The acetylene system is purged with nitrogen before start if the system has been without pressure. Under normal conditions the compressor stops with the acetylene pressure remaining in the whole system. 2. The compressor is equipped with a suction pressure indicator/alarm, which will trip the compressor before atmospheric pressure is reached in the system. Possible leakage points are checked visually. This prevents the entrance of air in the system.
8	Safety valve opens	The safety valve outlets are piped outdoors to a safe location. No consequence in-doors	No action required

Item	Detail and /or activity	Failure cases with a possibility to ignite an explosive atmosphere	Comments, precautions etc.
9	Emptying of water separator	Water and some oil residuals from compressor and drier are piped to a separator where the acetylene is brought back to the suction line of the compressor. The water/oil mixture is further piped to a oil/water separator connected to the open air by a pipe above roof. The separated water is emptied to the drain system and the oil is emptied into a bucket. The oil and water levels are visually checked (sight glass) according to procedure. When established levels are reached, a manual valve is opened for water or oil as appropriate.	Small amounts of acetylene of atmospheric pressure can be released if un-intentionally the water or oil valve is not closed after emptying the liquid
10	Water/oil/acetylene collector accidentally filled with water/oil	The manual emptying as requested by work instruction and maintenance schedule is not done.	This unlikely event will not cause any gas release in the room and the compressor will automatically trip when the water enters the compressor inlet system.
11	Water/oil separator accidentally filled with water/oil	The manual emptying as requested by work instruction and maintenance schedule is not done	The gas and liquid will be released at the roof through the piping system. Very unlikely since the separator is fed when a manual valve at a collector is opened
12	Start up and shut down		See 7 above
13	Maintenance and repair	Accidental gas release if wrong shut down procedure is used. Possible spark generation when using tools	Maintenance and repair of the compressor is only done after a shut down and purge of the system. A work permit is issued after clarifying that the area is free of gas.

Classification of hazardous areas – acetylene plant

Item	Area and/or activity	Zone	Release mechanism.	Ignition risk and consequence	Comments and references
1	**Carbide storage and handling areas**				
1.1	Storage of carbide Turnbin containers, outdoors and indoors area	None	The Turnbin container has only one valve in the bottom and is tight. No risk of water ingress and acetylene generation. The container is purged with nitrogen at the filling of carbide.	-	Ordinary, non ex-proof equipment can be used at handling
1.2	Outdoors transport of containers	None	The design of Turnbin will not allow any water ingress	-	Ordinary, non ex-proof equipment can be used
1.3	Generic in carbide handling room	2	The carbide area is open to generator room. A major accidental release in the generator room will therefore spread to carbide room	Very low ignition risk, see general precautions. An ignition can cause a room explosion and considerable damage. Also injury if operator in the room	Water is not allowed in the carbide room and the entrance is marked correspondingly.
1.4	Transport/handling of containers in carbide handling room	None	No release of flammable gas	An accidental drop of steel container against concrete floor might cause a spark possible to ignite a cloud according to 1.3. Extremely low risk	Pneumatic crane or manual lifter for ex areas is used. Maintenance schedule of crane and equipment is implemented.
1.5	Purging of Turnbin	None	The purge gas nitrogen is vented above roof including any residual acetylene in the Turnbin	-	The vented gas is not flammable why there is no hazardous zone around the outlet above roof
1.5	Cleaning of indoors carbide handling area	None	No water available or must be brought into the area. Only brushes (spark free) used for cleaning.	Very low ignition risk due to spark free brushes, see general precautions. An ignition caused by acetylene generated by carbide residuals on the floor can only cause minor fire without any serious consequence	The area is not hazardous since the possible flammable gas volume occupies < one ten thousands of room volume. See ref. 12.3

Item	Area and/or activity	Zone	Release mechanism.	Ignition risk and consequence	Comments and references
2	**Acetylene generation area (low pressure area)**				
2.1	Generic	2	A single failure of valves, water seal at generator, blockage in the generator, etc. might cause a release of acetylene in the room.	No ignition sources available in the room. Only low pressure acetylene.	The release will be noticed by the operator and the process stopped immediately. Natural ventilation by low and high openings
2.2	Valves, pipe connections, water seal, etc.	-	Small insignificant leakage from the low pressure system can occur and persist during normal operation	See 2.1	Natural ventilation in the room. The very small possible leakage will not cause any zone 1 area.
3	**Lime bin**				
3.1	Lime bin	1 2	The residual lime is piped from generator to the bin and contains dissolved acetylene and maybe non-reacted carbide residue. A post-generation of acetylene might occur in the bin and temperature variation will release the dissolved acetylene Zone 1 only 0.1 m above the surface of the lime sludge. Accidentally a significant amount of non-reacted carbide might be dumped in the bins Zone 2, from the top of the bin walls down to the zone 1 level	The lime bin is in the open air, that is good ventilation. No ignition source available	
3.2	Outlet of lime sludge pipe from generator	1	See 3.1. Zone 1 0.1 m around pipe outlet and jet of liquid		
4	**Gas holder - indoors**				
4.1	Generic	2	Acetylene escaping at emergency emptying or internal water seal failure is piped above roof. The external water seal might fail and release acetylene.	There is no ignition source available in the room. Natural ventilation by low and high openings	
4.2	Valves, water seal	1	Minor evaporation of acetylene from water seal. Zone 1, 0.2 m above water seal surface	No ignition source Natural ventilation by low and high openings	No significant leakage from the low pressure system can occur and persist during normal operation

Item	Area and/or activity	Zone	Release mechanism.	Ignition risk and consequence	Comments and references
5	**High pressure area – compressors and driers**				
5.1	Generic	2	Valve failure, leaking joints, and other accidental scenarios might cause a release of acetylene in the room.	The release will be noticed by the operator, the process will be emergency stopped and all persons will leave the room. No ignition sources available in the room. Natural ventilation by low and high openings	The acetylene pressure in piping system and cylinders is < 25 bars. The room has a mechanical ventilation with >4 air changes/hour
5.2	Valves, pipe connections, etc.	1	Small leakage from the high pressure system can occur and persist during normal operation Zone 1, 0.1 m around valves, connections etc. on high pressure piping corresponding to a release source of 0.1 mm equivalent diameter	See 5.1	See section 8 above.
5.3	Emptying of cylinders	1	See 5.2	See 5.2	
5.4	Safety valve release, emergency emptying of system	-	All these release sources are piped outdoors, see below	-	
5.5	Emptying of water separator	1	The water from the compressor contains some dissolved acetylene and the valve is manually shut off when the water ends. Small amounts of acetylene of atmospheric pressure can be released occasionally.	The water separator is open to the atmosphere through a piping above roof.	
6	**Cylinder filling room**				
6.1	Generic	2	Valve failure, ruptured flexible hose if cylinder falls, bad connection to cylinder valve and other accidental scenarios might cause a release of acetylene in the room.	No ignition sources available in the room. Natural ventilation by low and high openings. Low risk that the gas stream will be ignited due to electrostatic discharge due to gas velocity.	The release will be noticed by the trained operator, who will initiate an emergency action by stopping the process and evacuating the room
6.2	Valves, pipe connections, etc.	1	Small leakage from the high pressure system can occur and persist during normal operation Zone 1, 0.2 m around valves, connections etc. on high pressure piping	See 6.1	

Item	Area and/or activity	Zone	Release mechanism.	Ignition risk and consequence	Comments and references
6.3	Air ingress in hoses before connection to cylinder	-	If air has entered the hose an adiabatic compression of the air/acetylene mixture at start of filling can cause an ignition	The hose might rupture releasing acetylene	The hoses are equipped with check valve at cylinder connector. Valves are opened before the pressure is increased
6.4	Acetylene release at disconnection	1	The 25 bar acetylene between cylinder valve and check valve will be released at disconnection of hose.	The escaped acetylene will cause a zone 1 < 0.1 m	
6.5	Acetoning of cylinders	1	A minor leakage, 0.5 g/s can occur during acetone filling, that is 30 g can be released and wetting the cylinder and valve. At immediate vaporizing, this can cause a LEL zone1 0.5 m around the cylinder from the top down to the floor.	The acetoning is done manually and there is an acetone supply emergency stop at the work place. Very low ignition risk	See section 8
6.6	Emptying of cylinders	1	See 6.2	-	
6.7	Safety valve release, emergency emptying of system	-	All these outlets are piped above roof		See outdoors area
7	**Acetone storage / pump room**				
7.1	Pneumatic pump	1	The whole room is classified as zone 1 since a small leakage might cause an explosive atmosphere in the small room with rather poor ventilation.	Low ignition risk. When changing acetone drums non-exproof hand driven pallet lifter can be used after shut off of pump and check of atmosphere (Acetone content < 25% of LEL)	The acetone drum and a pneumatic pump is located in a separate room, 30 m^3, with natural ventilation The pneumatic pump is risk assessed as mechanical equipment and no possible ignition source has been identified. (This risk assessment is not included in this document)
8	**12.10.1.1 Storage of acetylene cylinders outdoors but under roof at the building's dock**				
8.1	Cylinder storage and handling at outside dock area with roof	2	Several openings to the acetylene cylinder filling room. Any major release in the room will spread to the dock area	Low risk of ignition. At a major release inside the building, all persons will leave the area and activate emergency stops	

Item	Area and/or activity	Zone	Release mechanism.	Ignition risk and consequence	Comments and references
9	**Outside of doors, ventilation openings and other openings to high and low pressure buildings and other classified indoors areas**				
9.1	Doors and other openings in the building	2	See above for possible major releases Zone 2 1 m around door and window openings if no roof above (see 8.1)	No ignition source in the area. At a major release inside the building, all persons will leave the area and activate emergency stops	According to informative annex, EN 60079-10:1996, § ND.6.2.2.4.2
9.2	Ventilation duct opening	2	See above for possible major releases Zone 2 1 m around door and window openings if no roof above (see 8.1)	Low risk of ignition.	According to informative annex, EN 60079-10:1996, § ND.6.2.2.4.2
10	**Outdoors release points from vents, safety valves, etc.**				
10.1	Outlets from safety valves	1 2	Zone 1, 1 m around pipe outlet, diam. of safety valve 6 mm, pressure <25 bar. Zone 2, 3 m around pipe outlet	-	According to informative annex, EN 60079-10:1996, § ND.6.2.2.4.2
10.2	Emergency emptying of gas holder	2	Zone 2, 5 m around pipe outlet		For calculation, see note 10.2 below
10.3	Emergency emptying of high pressure (25 bars) system	2	Zone 2, 6 m around pipe outlet		For calculation, see note 10.3 below
10.4	Residual emptying of acetylene cylinders	1 2	Zone 1, 0.5 m around pipe outlet Zone 2, 1.5 m around outlet	No ignition sources around vent outlet at roof	Cylinders are emptied to gas holder. Only residual pressure (300 mmWG or 0.03 bar) in piping system above roof
11	**Shut down, start up and maintenance**				
11.1	Shut down	-	None. The piping system or any equipment must not be opened without purging. Work permit is issued for the opening and maintenance after check of purging etc.	None	At normal compressor stops the acetylene pressure will remain in the whole system. When the system or any part of it will be opened to the atmosphere, the system will be purged with nitrogen as a part of the shut down procedure.

Item	Area and/or activity	Zone	Release mechanism.	Ignition risk and consequence	Comments and references
11.2	Start up	-	Accidental release might occur when equipment or pipes have been dismantled and connected again but since start up is done with nitrogen any release will be eliminated before the system is pressurised with acetylene	Failure of purging can cause an explosion of the acetylene / air mixture in the system. Low pressure part of the installation can rupture and injure operator.	At normal compressor stops the acetylene pressure will remain in the whole system. When the system or any part of it has been opened to the atmosphere, the system will be purged with nitrogen as a part of the shut down /start up procedure.
11.3	Repair and maintenance	-	Accidental release when disconnecting pipes or equipment. Remaining flammable gas in equipment /pipes.	Very low risk. If released acetylene is ignited, the operator can be injured	Job risk assessments and formal routines for maintenance and repair are implemented including purging and written work permits.

Note: 10.2 Calculations using the Phast model, Weather F Stability 0.6 m/s. Source a 50 mm vertical pipe with a weather protection “hat” ending 1 m above roof, acetylene pressure 0.03 bar, 15^{o}C. The “hat” will cause that the gas is released in all directions and the modelling assumes a release in four perpendicular directions, each ¼ of total flow.
Note: 10.3. Release of 0.1 m^3 gas, 25 bar. Pipe diameter 25 mm, valve opening corresponds to 6 mm diam. The outlet is located 1 m above roof, directed downwards.

Appendix 3: Classification of hazardous areas – Open air storage of acetylene gas cylinders

Item	Area and/or activity	Zone	Release mechanism.	Ignition risk and consequence	Comments and references
1	Leaking valve spindle or valve neck thread	None	All valves are checked for leakage after filling. Very low probability that valve suddenly starts to leak. Small release rate, see section 8	Neglectable ignition risk. Mobile electric equipment (mobile phones) very close to valve might ignite.	If ignited, only small flame which will not affect surrounding cylinders. The possible volume of explosive atmosphere is << 10 litres and consequently not a hazardous area.
2	Leaking valve outlet	None	All valves are checked for leakage after filling. All valves have sealing nut on valve.	Not applicable	See section 8 when sealing nuts are not used.
3	Shell leakage caused by pit corrosion or weld defect	None	Extremely unlikely event. Cylinders are regularly inspected.	Low ignition risk. Mobile electric equipment (mobile phones) close to cylinder might ignite. Also handling, manually or by truck can cause ignition	Un-likely but possible that an ignition will heat up other cylinders and cascade the fire.
4	Shell damaged by FLT fork.	None	Very unlikely. Cylinders handled by FLT are stored in pallets. Strength of cylinder shell good. FLT drivers properly trained	Very high ignition risk	
5	Inadvertent opening of valve at handling	None	Very unlikely. Cylinders have caps and sealing nut at valve outlet. Operator will immediately close valve if release occurs	Medium ignition risk	Moving cylinders by rolling is not allowed when cylinders are not equipped with a cap.
6	Cylinder falls over	None	Unlikely event. No release. Cylinders have caps	Not applicable	
7	Vehicle impact	None	The possibility of an impact low due to traffic control at site. Very unlikely that a impacted cylinder will leak	Not applicable	
8	Malicious damage of cylinder	None	The storage area is fenced and visitors are controlled. Insignificant risk of leakage	Not applicable	

Note: This appendix can also be used for other permanent flammable gases when the leak scenarios are in line with the assessment done for acetylene cylinders