HAZARDS OF INERT GASES AND OXYGEN DEPLETION

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1 Introduction

AIGA is very concerned about the accidents that industrial gas companies and users of inert gases continue to report each year, where the direct cause has been lack of oxygen resulting in asphyxiation. AIGA identified that existing information on the hazards of inert gases was not sufficiently directed at the users who were most at risk. This document sets out the essential information that is necessary to prevent asphyxiation accidents involving inert gases.

2 Scope and purpose

It is intended that this document is used as a training package suitable for supervisors, line managers, direct workers and users wherever inert gases are produced, stored, used, or where oxygen depletion could otherwise occur.

This document has 4 parts:

The main document is intended for line managers and supervisors and gives the background of the subject, the typical description of oxygen deficiency accidents and the recommended rescue preparations to be in place in case of accident.

Appendix A is a simplified summary of the main document, designed to be reproduced as a pamphlet for sharing with workers and end users.

Appendix B gives an introduction to rescue considerations from normally accessible rooms, confined spaces or pits and trenches.

Appendix C lists some actual accidents that have taken place in recent years, which can be used as examples to underline the potentially fatal hazards of inert gases.

Appendix D gives an example of a warning sign or poster to highlight the hazards of inert gases and asphyxiating atmospheres.

3 Definitions

Asphyxiation: the effect on the body of inadequate oxygen, usually resulting in loss of consciousness and/or death. This is also known as suffocation or **anoxia**.

Asphyxiant: any material which reduces the amount of available oxygen either by simple dilution or by reaction.

Inert gas: A gas that is not toxic, which does not support human breathing and which reacts little or not at all with other substances. The common inert gases are nitrogen and the rare gases like helium, argon, neon, xenon and krypton.

Flammable gas: a gas whose major hazard is flammability. Note that all flammable gases also act as asphyxiants.

User: for the purpose of this document this term covers any individuals, companies or other organisations that make use of the products sold by industrial gas companies. Users may be, but are not necessarily, customers.

4 General Information about Inert Gases and Oxygen Depletion

In spite of the wealth of information available, such as booklets, films and audio-visual aids, there are still serious accidents resulting in asphyxiation caused by the improper use of inert gases or by oxygen depletion. It is therefore absolutely essential to draw attention to the hazards of inert gases and oxygen depletion. Accidents due to oxygen depleted atmospheres are usually very serious and in many cases fatal.

Although carbon dioxide is not an inert gas, most of the information in this document is applicable as it too will cause oxygen depletion. However, the specific hazards and physiological effects of carbon dioxide are more complex than those of inert gases. This document does not cover these aspects. (See IGC Doc. 67 "CO2 cylinders at user's premises" for more details about the additional hazards of carbon dioxide).

4.1 Oxygen is essential for life

Oxygen is the only gas that supports life. The normal concentration of oxygen in the air we breathe is approximately 21 %. Concentration, thinking and decision-making are impaired when the oxygen concentration falls only slightly below this norm. These effects are not noticeable to the affected individual.

If the oxygen concentration in air decreases or, if the concentration of any other gases increase, a situation is rapidly reached where the risks of asphyxiation are significant. For this reason any depletion of oxygen below 21 % must be treated with concern:

Asphyxia – Effect of O_2 Concentration (from NL/77 Campaign against Asphyxiation)

O_2 (Vol %)	Effects and Symptoms
18-21	**No discernible symptoms** can be detected by the individual. A risk assessment must be undertaken to understand the causes and determine whether it is safe to continue working.
11-18	Reduction of physical and intellectual performance **without the sufferer being aware**.
8-11	Possibility of fainting within a few minutes without prior warning. **Risk of death below 11%.**
6-8	Fainting occurs after a short time. **Resuscitation possible** if carried out immediately.
0-6	Fainting almost immediate. **Brain damage**, even if rescued.

***WARNING**: The situation is hazardous as soon as the oxygen concentration inhaled is less than 18 %.*

With no oxygen present, inhalation of only 1-2 breaths of nitrogen or other inert gas will cause sudden loss of consciousness and can cause death.

4.2 Inert gases give no warning

It is absolutely essential to understand that with inert gases such as nitrogen, argon, helium, etc., asphyxia is insidious - there are no warning signs!

- Inert gases are odourless, colourless and tasteless. They are undetectable and can therefore be a great deal more dangerous than toxic gases such as chlorine, ammonia, or hydrogen sulphide, which can be detected by their odour at very low concentrations.
- The asphyxiating effect of inert gases occurs without any preliminary physiological sign that could alert the victim. Lack of oxygen may cause vertigo, headache or speech difficulties, but the victim is not capable of recognising these symptoms as asphyxiation. Asphyxiation leads rapidly to loss of consciousness – for very low oxygen concentrations this can occur within seconds.

4.3 Inert gases act quickly

In any accident where the supply of oxygen to the brain is affected, prompt emergency treatment is critical. Proper medical treatment (resuscitation) if given quickly enough can prevent irreversible brain damage or even death in some instances.

Furthermore, and this is often poorly understood, the emergency rescue procedure to save the victim must be carefully thought out in advance to avoid a second accident, where members of the rescue team can become victims. Unplanned interventions resulting in the fatalities of would-be rescuers are sadly not unusual.

4.4 The ambiguity of inert gases

Everyone, particularly customers, must be aware of the ambiguity of the expression “inert gas” (sometimes called “safety gas”, when it is used to prevent fire or explosion), whereby an “inert gas” is often perceived, understood and wrongly taken to be a harmless gas!

4.5 Watchfulness with regard to inert gases and oxygen depletion

Considering the hazards mentioned above, it is essential to provide all those who handle or use inert gases (gas company personnel as well as customers) with all the information and training necessary regarding safety instructions. This includes the means of prevention and procedures to be respected to avoid accidents, as well as planned rescue procedures to be implemented in the event of an accident.

5 Some typical situations with inert gas and/or oxygen depletion hazards

5.1 Confined or potentially confined spaces and enclosures

Confined, restricted or enclosed spaces are particularly dangerous situations where an inert gas may be **normally present** (inside a process vessel), may have **accumulated** (from leaks or vents) and/or because the space has not been **adequately vented or purged**, and/or the renewal of air is poor or **ventilation is inadequate**.

Examples of such spaces include:

- <u>Confined spaces</u>: tanks, vessels, reservoirs, the inside of “cold boxes” of liquefaction equipment, cold storage rooms, warehouses with fire suppressant atmospheres, etc.
- <u>Enclosures</u>: analyzer or instrument cabinets, small storage sheds, temporary/tented enclosures, or spaces where welding protective gas is used, etc

The precautions required for safe access by personnel will be different in each of these cases as explained in Appendix B.

5.2 The use of inert cryogenic liquids

It is to be noted, that the use of inert cryogenic liquids such as nitrogen or helium is accompanied by two primary hazards:

- The fluids are very cold (-196°C for nitrogen and -269°C for helium) and can cause serious cold burns on contact with the skin.
- Once vaporised both products will generate a large volume of cold inert gas (e.g. 1 litre of liquid nitrogen will yield 680 litres gaseous product) that will displace ambient air, causing oxygen deficiency and may accumulate in low points.

In processes where cryogenic liquids are handled and vaporisation takes place, special care must be taken to avoid situations where personnel are exposed to oxygen deficiency. These may be in <u>rooms which people regularly enter or work in</u>.

Examples of such spaces include:

- The internal rooms of a building where cryogenic liquid cylinders/dewars are filled and/or stored,
- Laboratory rooms,
- Elevators (lifts) used for transport of dewars,
- Rooms where liquid nitrogen food freezers are operated. (Tunnel, cabinet)
- Rooms where Magnetic Resonance Imaging (MRI) scanner or other liquid helium cooled equipment is used
- Rooms in which cryogenic de-flashing equipment is operated.

Notes: Due to the extremely low temperature of liquid helium a secondary hazard may exist where the product is flowing through hoses or pipes. In this case it is possible for the components of air to liquefy on the outside of the hose/pipe, possibly leading to pooling of liquid containing levels of enriched oxygen. [See Ref. 7].

5.3 Areas near where inert gases are vented or may collect

The risk of asphyxiation can arise, even outdoors, in the vicinity of:

- Gas leaks
- Vent exhausts
- Outlet of safety valves and rupture disks
- Openings of machines in which liquid nitrogen is used for freezing
- Blind flanges
- Near manways/access to vessels or purged enclosures (e.g. ASU cold boxes, electrical enclosures)

Any cold gas or heavier-than-air gas will travel or “flow” – often unseen - and collect even outdoors, in low spaces such as:

- Culverts
- Trenches
- Machine pits
- Basements
- Elevator (lift) shafts

Similarly and just as dangerously lighter-than-air gases (e.g. helium) will rise and collect in unventilated high points such as:

- Behind false ceilings
- Under a roof

5.4 Use of inert gas instead of air

Planned Use

In many workplaces, there are often compressed inert gas distribution networks that are used for process applications, safety or instrumentation purposes, e.g. inerting/purging of reactors or using nitrogen as a pressure source to operate pneumatic equipment (such as jackhammers) or as instrument fluids.

Additionally, nitrogen is often used as either a backup to, or substitute for, an instrument air system. Where it is used as a backup supply in case of instrument air compressor failures it is quite common to find a nitrogen supply connected to an air supply by means of isolation valves, It must be appreciated that most pneumatically operated instruments vent continuously and that the vented nitrogen may accumulate in poorly ventilated control panels/cubicles or plant rooms. This can present a serious asphyxiation risk. Where nitrogen is used temporarily to substitute for compressed air in this way, it must be done under strictly controlled conditions such as a permit to work, and all relevant personnel shall be informed.

Improper Use

In situations where piped breathing systems exist there is always the potential for employees, who are insufficiently trained or not familiar with the systems, to connect the breathing apparatus to a nitrogen system with fatal results. Such systems must be clearly marked and ideally the breathing air system should have a dedicated connection type not used elsewhere in the premises.

5.5 Dangers of improper inhalation (abuse) of inert gases

There has been increased of reporting and presentations in TV-programmes on the careless approach and dangerous misuse of breathing in gases such as helium and other inert rare gases. The media reports in particular trivialise the effects of inhaling helium to achieve a very high-pitched voice. Inhalation of helium can lead to unconsciousness, cessation of breathing and sudden death.
[See Ref. 6 for more information]

6 Hazard mitigation and preventive measures

6.1 Information, training

All persons who handle or who use inert gases shall be informed of:
- Safety measures that should be adopted when using gases.
- The hazard represented by the release of inert gases in to the working space and the potential for oxygen depletion.
- Procedures to be observed should an accident occur.

This information and training should be systematically and periodically reviewed in order to ensure that it remains up to date and appropriate for the hazards identified.

6.2 Proper installation and operation

Equipment for the manufacture, distribution or use of inert gas must be installed, maintained and used in accordance with:
- All applicable regulations.
- The recommendations of the supplier
- Industrial gas industry standards and codes of practice

Newly assembled equipment for inert gas service must undergo a proof test and be leak-checked using suitable procedures.

Each inert gas pipeline entering a building should be provided with an easily accessible isolation valve outside the building. Ideally such valves should be remote activated by push buttons or other safety monitoring equipment.

Discontinued inert gas lines shall be physically disconnected from the supply system when not in use.

At the end of each work period, all valves that isolate the inert gas should be securely closed to avoid possible leakage between work periods.

6.3 Identification and safeguarding of potentially hazardous areas

Measures should be taken to identify potentially hazardous areas, or restrict access to them, e.g.
- Warning signs should be displayed to inform of an actual or potential asphyxiation hazard (An example is shown in Appendix D). The warning sign should be associated with measures to prevent unauthorised entry to the areas.
- Temporary or permanent barricades, for example physical lock on vessel manway or barricades around temporary excavations.
- Communication to site personnel to ensure awareness and understanding.

6.4 Ventilation and atmospheric monitoring for inert gases and oxygen deficiency

Typically there are three situations where the need for ventilation or atmospheric monitoring must be assessed in order to avoid asphyxiation accidents from inert gases and/or oxygen depletion:

6.4.1 Ventilation/ monitoring of rooms which people regularly enter or work in

Examples in this category would include:
- Rooms containing **inert gas pipelines** with possible leaks such as compressor houses, control rooms (with control/analyser panels).
- Rooms where **inert cryogenic liquid** is used or stored (see 5.2 above)

Building/room size, ventilation capacity, system pressures, etc. must be determined for each specific case. The following guidelines can be applied to ventilation system design:
- Ventilation must be continuous while the hazard exists. This can be achieved by interlocking the ventilation system with the process power supply.

- Ventilation system design should ensure adequate air flow around the normal operating areas.
- Good engineering practice indicates a minimum ventilation capacity of 6-10 air changes per hour.
- The use of devices to indicate correct system operation, such as:
  - Warning lights
  - “Streamers” in the fan outlet,
  - Flow switches in the suction channels (monitoring should not rely only upon secondary controls such as “power on” to the fan motor).
- Exhaust lines containing inert gases shall be clearly identified, and should be piped to a safe, well ventilated area outside the building, away from fresh air intakes.
- Consideration should be given to the use of workplace atmospheric monitoring, e.g. personal oxygen analyser or an analyser in the work area, location to be based on assessment of the areas described in 5.3.
- People working in or entering the area shall be aware of action required in event of alarms from atmospheric monitors or loss of ventilation.

6.4.2 Ventilation/ monitoring prior to entry into confined spaces or enclosures

As described in 5.1 above, these spaces would include enclosures or vessels which:

- Are not routinely entered and
- Are known to have contained inert gas or
- May contain inert gas or low concentration of oxygen
- Any vessel not known and verified to contain atmospheric air.

In these cases the following guidelines apply to prepare a safe atmosphere prior to entry:

- Sources of inert gas must be isolated from the space or enclosure by positive blinds or by disconnection of lines. Never rely only on a closed valve.
- The vessel or enclosure must be adequately purged with air (i.e. remove the inert gas and substitute with air).
  - It is necessary to have at least 3 complete air changes within the enclosure involved.
  - Purging shall continue until analysis confirms that the quality of the vessel atmosphere is safe for personnel entry. If there is any doubt that effective purging has taken place, the analysis should be made in the interior of the vessel by taking a sample at several locations by probe, or if this is not possible, by a competent person using a self contained breathing apparatus.
  - The purge system must ensure turbulence for adequate mixing of air and inert gas to take place (to avoid “pockets” of dense or light inert gases remaining or to avoid “channelling” of gases due to inadequate purging).
  - Removal of argon or cold nitrogen from large vessels and deep pits can be difficult due to the relatively high density of the gas compared with air. In that case the gas should be exhausted from the bottom of the space.
  - Ventilation should never be carried out with pure oxygen, but exclusively with air.
- Another method of removing inert gases is to fill the vessel with water and allow air to enter when the water is drained off.
- Oxygen content of the atmosphere in the enclosure/vessel shall be monitored continuously or repeated at regular intervals.
- Consideration should also be given to the use of personal oxygen monitors.

Where a safe atmosphere cannot be created and confirmed, then the task must only be performed by competent personnel provided with a positive breathing air supply.

6.4.3 Ventilation/monitoring for entry into other spaces where inert gases may be present

This type of confined space is one that has any of the following characteristics:

- Limited opening for entry and exit
- Unfavourable natural ventilation

Examples are listed in sections 5.1 and 5.3 and include;

- Underground works
- Trench/pit deeper than 1 metre
- Small rooms where gases are stored but not designed for continuous worker occupancy.

In the majority of these cases the presence of inert gases is not anticipated when entering such spaces. However, the one essential safeguard in all cases is to sample the atmosphere in the room, enclosure, trench, pit, etc. for oxygen prior to any entry. Where appropriate a continuous fixed point monitoring device should be used.

The fact that an oxygen deficient atmosphere is not normally expected is the greatest danger.

6.4.4 Notes on purging requirements

The guidance for air changes, mentioned in section 6.4.2, is valid where nitrogen is the inert gas involved because its density is very near to that of air and oxygen.

If the gas to be purged has a density very different from the density of air, such as helium, argon or carbon dioxide, etc. the ventilating air may not adequately mix and the purge may be inadequate.

For inert gases of this type the volume of gas to be displaced (air changes) must be at least 10 times that of the volume involved. The preferred method of removal of very dense gases (e.g. argon or cold nitrogen vapour) is to suck out the gas from the bottom of the space.

In the presence of toxic or flammable gases, it is mandatory to perform an additional analysis of the gases present in the confined space, before entry of personnel. For obvious reasons, the measurement of only the oxygen content is not sufficient in this case. All other dangerous toxic or flammable gases must also be analysed.

In the specific case of flammable gases, a nitrogen purge must be used first to prevent any explosion risk and then subsequently purge with ventilating air.

6.5 Testing of oxygen content

Historically, the need to check that an atmosphere is respirable has been considered to be of the greatest importance. In the past, simple means were employed, such as, for example, the lighted candle or the canary bird.

Currently, various types of oxygen analysers are available, which are often reliable and simple and to operate. The selection of the type of apparatus depends on the nature of the work in the place to be monitored (presence of dust, temperature and humidity, multiple detectors, portable equipment, etc.).

- Oxygen analysers are critical equipment and must be properly maintained and calibrated in order to sufficiently reliable. It is also important to ensure that fixed and portable detectors are properly positioned to measure a representative sample of the atmosphere.
- A simple way check to confirm that an oxygen analyser is operating properly before use is to measure the oxygen content of the open air (21 %). This check should be part of the work permit requirements.
- All oxygen analysers should be fitted with an alarm device to indicate possible defects (e.g. low battery).
- The minimum safe oxygen concentration for entry into a space that is being controlled or measured because of the risk is 19.5 % oxygen. There are applications with oxygen concentrations below 19.5 % where entry is permitted provided that further precautions are taken in accordance with proper risk assessment and national regulations (e.g. fire suppression). [See Ref 4]

6.6 Work permit

For certain types of work, safety instructions and a special work procedure must be set up in the form of a work permit, this particularly relates to any form of confined space entry. [See Ref 8]
This procedure is necessary during work carried out by subcontractors in air separation cold boxes, or where vessel entry is required.

It is important that a work permit procedure deals with the detailed information that must be given to involved personnel before the start of work. This information should include contractual conditions together with documented risk assessments, procedures and the training of site workers.

6.7 Lock-out Tag-out procedure

To ensure any sources of inert gas have been properly isolated, the implementation of a stringent, formal lock-out and tag-out procedure is necessary before safe entry into a confined space.

6.8 Protection of personnel

The type of work to be performed, the layout of the premises and the assessment of potential rescue scenarios will determine the provision of additional protective measures. This additional protection should include organisational measures and/or safety equipment such as:

- Fixed or personal oxygen monitoring equipment
- The wearing of a harness so that the worker can be easily and rapidly taken out of an enclosed space in the case of an emergency. Preferably, this harness is to be connected to a hoist to facilitate removing the victim. (In practice, it is extremely difficult for one person to lift up another person in the absence of a mechanical aid of some kind.)
- The provision of an alarm system in case of an emergency.
- The wearing of a self contained breathing apparatus (not cartridge masks, which are ineffective in a case of lack of oxygen).
- In the case of work inside a confined space, a standby person should be placed on watch outside the space/vessel.
- Having a self contained breathing apparatus on stand by.
- The wearing of other personal protective equipment such as safety boots, hard hat, goggles or gloves, depending on the hazards of the location and task.

7 Confined space entry

The employer has an overriding duty to ensure that tasks in confined spaces with potentially hazardous atmospheres are performed **without entry** whenever this is practical. Only if it there is no practical alternative shall people be required to enter confined spaces.

Any entry into a confined space or enclosure with a potentially hazardous atmosphere shall be carefully controlled and have:

- A written method statement for the work to be undertaken with the space.
- A documented risk assessment for performing this task in this particular vessel.
- Formal, stringent lock-out and tag-out procedures.
- An assessment of potential scenarios where rescue may be required.
- An emergency (rescue) plan to deal with any possible accident scenario related to entry in to the enclosure or vessel.
- Rescue personnel and equipment should be available as required by the rescue plan.
- Trained and competent personnel in roles of; entrant, stand-by watch, rescue team (where required) and supervisor/permit issuer.
- A safe work permit issued and signed before entry is allowed.

This document is not a detailed procedure for confined space entry, but focuses on the considerations which are important where there is an actual or potential hazard from inert gases or oxygen deficiency.

8 Rescue and first-aid

Awareness training in the hazards of inert gases and oxygen deficient atmosphere is of vital importance for everyone who might enter a space or who might discover and affected person in a space with potentially asphyxiant atmosphere, in order to prevent subsequent fatalities as result of “unplanned rescue” attempts.

Training in rescue work is fundamental since quickly improvised rescue without the formality of a procedure, often proves to be ineffective, if not catastrophic, i.e. the rescue worker lacking foresight becomes a second or even a third victim. This is one of the most common causes of multiple fatalities in cases involving asphyxiation.

8.1 Basic rules

If a person suddenly collapses and no longer gives any sign of life when working in a vessel, a partially enclosed space, a trench, a pit, a small sized room, etc., it MUST be assumed that the person may lack oxygen due to the presence of an inert gas (which is, as mentioned, odourless, colourless and tasteless):

WARNING: *the discoverer must assume that* ***his life is at risk*** *entering the same area!*

The risk is that the rescuer will become the second victim, which obviously must be avoided at all costs. Ideally he should raise an alarm and call for assistance so that a prepared rescue can be carried out.

Rescuers intent on saving a possible asphyxiation victim should only do so if they have the necessary equipment, have been suitably trained, have proper assistance and support.

8.2 Rescue plan elements

The method of rescue will be determined by the access to particular space. If practical a non-entry rescue is preferred. Appendix B lists the considerations which should be given to rescue plans from three different situations:

- Rescue from normally accessible rooms
- Rescue from Confined Spaces
- Rescue from pits, trenches or excavations

In each case the Rescue plan must have elements which address:

- How the alarm is raised
- Identification of possible rescue scenarios (not only for low oxygen effects)
- Any scenarios in the surrounding work place which may or may not require immediate exit from the space (e.g. site evacuation in event of fire elsewhere)
- Stand-by watch trained to keep visual and verbal contact with the entrant and to ensure the entrant exits the space if symptoms of oxygen deficiency are suspected or observed
- Any assistance which may be needed/given from outside the space to help entrant escape from the space, without further entry.
- Re-checking/confirmation of atmosphere prior to rescue
- Manpower and equipment required to move unconscious person from that space
- Provision of first aid/medical treatment (e.g. resuscitation and/or oxygen treatment) inside the space if necessary
- Safe access by rescue and/or medical personnel if necessary
- How to make the space safe/prevent further injury after the rescue.

8.3 Equipment

A successful rescue action may need some of the following equipment. The actual needs must be assessed as part of the rescue plan and made available and accessible during the confined space work:

- A portable audible alarm devices, e.g.; personal horn, whistle, klaxon etc. to alert nearby people that assistance is required.
- Telephone or radio at the work site so that an alarm can be raised in event of problems
- A safety belt or harness connected to a line
- Mechanical aid such as pulley, hoist, to extract the victim.
- Possibly a source of air or oxygen to ventilate the confined space, such as:
  - A compressed air hose connected to the plant compressed air network,
  - A ventilation device.

- Additional oxygen monitors for rescue team for re-checking conditions inside the space
- Positive pressure breathing air supply. This may be an externally fed breathing air system or self-contained breathing apparatus (SCBA).
  WARNING*: Cartridge masks for toxic gases are not suitable as they do not replenish missing oxygen.*
- A resuscitation kit supplied with oxygen for the victim. In general, such a kit includes a small oxygen cylinder, a pressure regulator, an inflatable bag, and a mask to cover both the nose and mouth of the victim.
- Stretcher to carry injured person out of the space, away from work place and/or to ambulance.

It should be noted that any equipment identified as necessary to carry out an emergency rescue from a confined space should be defined on the basis of a full risk assessment and the emergency plan developed from it. Where this equipment is not available, a rescue should not be undertaken.

8.4 Rescue training

Where an emergency plan considers that a rescue is to be performed, it is recommended that there is an annual programme of training including **practical rescue drills**. It is also a good practice to consider a rescue exercise before start of confined space work.

8.5 First Aid

Where there is a potential hazard from inert gases/oxygen deficiency it is advisable to have personnel available who are formally qualified to give first aid and/or perform **resuscitation** in the event of an accident. The simplest first aid treatment for someone suffering from effects of oxygen deficiency is to bring the affected person **into fresh air** – as long as it safe to do so!

In most countries additional training is required so that first aiders are qualified to **provide Oxygen** as medical treatment for anoxia and other conditions.

9 Conclusions

There are two essential points to remember related to oxygen deficiency accidents involving inert gases:

- Accidents resulting from oxygen deficiency due to inert gases happen unexpectedly and the reactions of personnel may be incorrect. To avoid this, all personnel who may work with, or may be exposed to, inert gases must have routine awareness training in respect of the hazards of these gases.
- Accidents involving asphyxiant atmospheres are always serious, if not fatal. It is absolutely necessary to carry out both regular and periodic awareness training sessions for all personnel, as well as rescue drills.

10 References

[1] CGA document SB-2 2007 Oxygen-Deficient Atmospheres

[2] EIGA Asphyxiation campaign documents 2003 – including Dangers of Asphyxiation leaflet; Oxygen Deficiency training presentation and Newsletter 77/xx

[3] Oxygen deficiency hazards. Video tape EIGA, 1997

[4] EIGA Position Paper PP-14: Definitions of Oxygen Enrichment/Deficiency Safety Criteria – August 2006.

[5] US Chemical Safety and Hazard Investigation Board website Video Room www.csb.gov

[6] EIGA position Paper PP-24: Abuse of Gases

[7] IGC Doc 004 /AIGA 005/10 : Fire Hazards of Oxygen and Oxygen Enriched Atmospheres

[8] IGC Doc 040 / AIGA 011/04 : Work Permit Systems

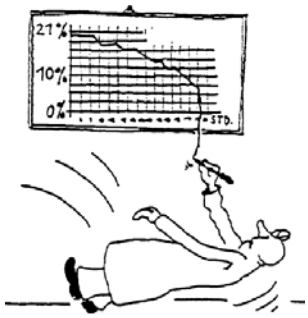
Appendix A: Summary for operators

1 Why do we need oxygen?

OXYGEN IS ESSENTIAL FOR LIFE
WITHOUT ENOUGH OXYGEN WE CANNOT LIVE

When the natural composition of air is changed, the human organism can be affected or even severely impaired.

If gases other than oxygen are added or mixed with breathing air, the oxygen concentration is reduced (diluted) and oxygen deficiency occurs.



If oxygen deficiency occurs due to the presence of inert gases (e.g. nitrogen, helium, argon, etc.) a drop in physical/mental efficiency occurs without the person's knowledge; at about 11 % oxygen concentration in air (instead of the normal 21 % concentration) fainting occurs without any prior warning.

Below this 11 % concentration there is a very high risk that death due to asphyxiation will occur within a few minutes, unless resuscitation is carried out immediately!

See also EIGA Safety Newsletter **NL/77 Campaign against Asphyxiation**

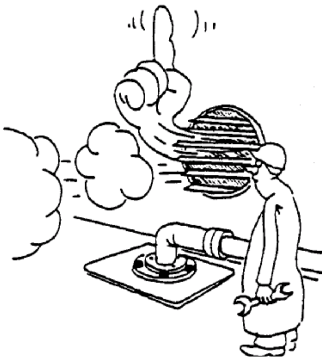
2 Causes of oxygen deficiency

a) When liquefied gases (such as liquid nitrogen, liquid argon, or liquid helium) evaporate, one litre of liquid produces approximately 600 to 850 litres of gas. This enormous gas volume can very quickly lead to oxygen deficiency unless there is adequate ventilation.

b) In the event of gases other than oxygen leaking out of pipe work, cylinders, vessels, etc., oxygen deficiency must always be expected. Checks should be made periodically for possible leaks.

Spaces with limited or inadequate ventilation (e.g. vessels) must not be entered unless air analysis has been made, safe conditions are confirmed and a work permit has been issued.

c) If work has to be carried out in the vicinity of ventilation openings, vent pipes or vessel man ways for example, personnel must be prepared to encounter gases with low oxygen concentration or without oxygen at all, being discharged from these openings.



d) Oxygen deficiency will always arise when plant and vessels are purged with nitrogen or any other inert gases.

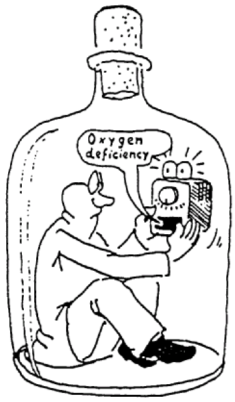
3 Detection of oxygen deficiency

HUMAN SENSES CANNOT DETECT OXYGEN DEFICIENCY

Measuring instruments give an audible or visual alarm of oxygen concentration and can indicate the oxygen content.

These instruments should always be tested in the open air before use.

If the presence of toxic or flammable gases is possible, specific instruments should be used.



4 Breathing equipment

Breathing equipment must be used in situations where oxygen deficiency has to be expected and which cannot be remedied by adequate ventilation.

Cartridge gas masks necessary for use in the presence of toxic gases (such as ammonia, chlorine, etc.) are useless for this purpose.

Recommended types of breathing equipment are:

- Self contained breathing apparatus using compressed air cylinders;
- Full-face masks with respirator connected through a hose to a fresh air supply.

NOTE:

- It should be born in mind that when wearing these apparatus, particularly with air filled cylinders, it might sometimes be difficult to enter manholes.
- Periodic inspection of the correct functioning of the equipment shall be carried out in accordance with local regulations.
- Users shall be trained and shall practice handling of the equipment regularly.

5 Confined spaces, vessels, etc.

Any vessel or confined space where oxygen deficiency is expected and which is connected to a gas source shall be disconnected from such a source:

By the removal of a section of pipe; or
by inserting a blanking plate before and during the entry period.

Reliance on the closure of valves alone might be fatal.

A space or vessel should be thoroughly ventilated, and the oxygen content shall be measured periodically before and during entry period.

If the atmosphere in such a vessel or space is not breathable, a qualified person shall use breathing equipment.

Permission to enter such a space shall be given **only after** the issue of an **entry permit** signed by a **responsible** person.

As long as a person is in a vessel or confined space, a watcher shall be present and stationed immediately outside of the confined entrance.

He shall have a self-contained breathing apparatus readily available.

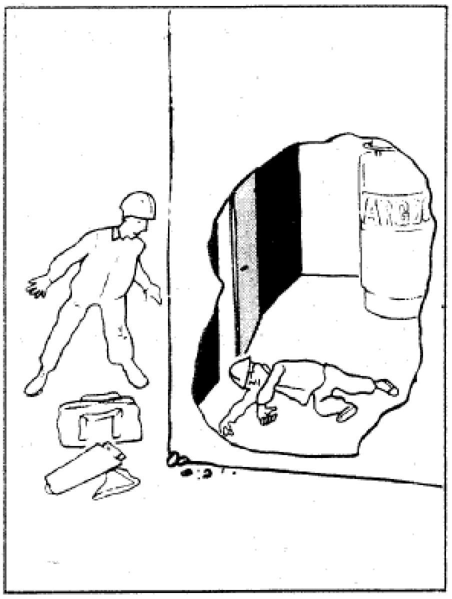
The person inside the confined space to facilitate rescue shall wear a harness and rope. The duty of the watcher should be clearly defined. A hoist may be necessary to lift an incapacitated person.

6 Emergency Measures

In the event of a person having fainted due to oxygen deficiency, he can only be rescued if the rescue personnel are equipped with breathing apparatus enabling them to enter the oxygen deficient space without risk.

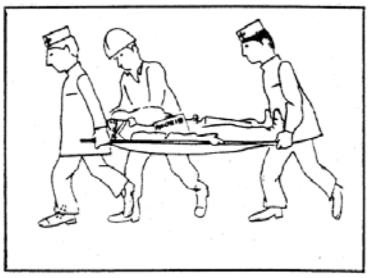
Remove the patient to the open air and administer oxygen without delay from an automatic resuscitator if available or supply artificial respiration. Guidelines and instructions for resuscitation can be obtained from the European Resuscitation Council (Internet Homepage: www.erc.edu).
Continue until patient revives or advised to stop by qualified medical personnel.

Appendix B1: Rescue considerations from normally accessible rooms



Planned Rescue Scenario:
If work is undertaken **on inert gas or cryogenic liquid systems within an enclosed room** it is suggested that:

- The entrant carries a personal oxygen monitor in addition to any fixed systems as the oxygen concentration may vary within the room if ventilation is absent or inadequate for the leak rate.
- The atmosphere within the space is checked before entry
- A stand-by watch is posted outside the space, to keep visual and verbal contact with the entrant and to ensure the entrant leaves the room unaided in case of early symptoms of oxygen deficiency
- The stand-by watch can raise an alarm by telephone or radio on event of problems
- The stand-by watch has Self Contained Breathing Apparatus (SCBA) ready so that he can safely enter the enclosed room to go to the assistance of, or to extract the victim if necessary.
- Unless a plan is in place so that the entrant can be safely removed by the standby-watch alone, then the rescue team should have been warned of the confined space entry work in progress, and be ready with Self Contained Breathing Apparatus (SCBA) and other equipment so that they can safely enter the Confined space to go to the assistance of, or to extract the victim if necessary.
- Plans have been made to obtain treatment/assessment from qualified medical personnel for the victim as soon as possible after he is retrieved from the room.

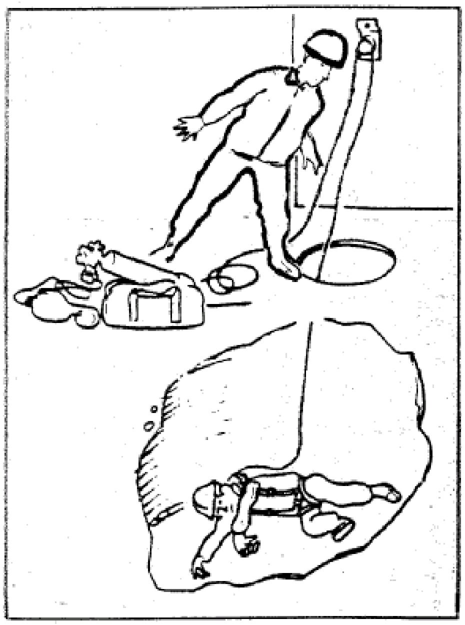


Unplanned Rescue Scenario:
If a person is found collapsed in a room where there is a potential inert gas leak / oxygen deficient atmosphere, then the discoverer must assume that **his life is at risk** entering the same area.
He should raise an alarm and call for assistance so that a prepared rescue can be carried out.

ONLY if the collapsed person can be reached, from outside the room should any consideration be given to extracting the victim from the space and bringing him out to fresh air and medical attention.

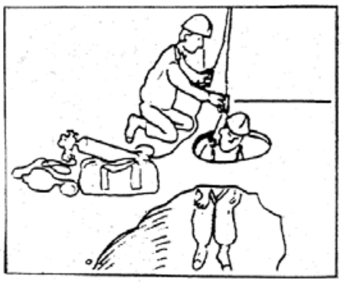
IF the victim has collapsed as a result of an oxygen deficient atmosphere and been there for any length of time it is very likely that he is dead and the discoverer's life is risked in vain.

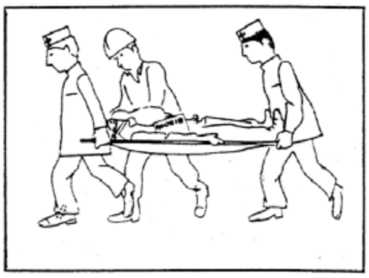
Appendix B2: Rescue considerations from Confined Spaces



Planned Rescue Scenario:
If work is undertaken within a **Confined Space** such as a vessel or a difficult access space, with potential inert gas/ oxygen deficient atmosphere, it is essential that:

- The atmosphere within the space is made safe, ventilated and checked before entry
- The entrant carries a personal oxygen monitor.
- If practical the entrant wears a body harness with life line, so that he can be removed from the space by persons outside. A hoist or other mechanical aid may be needed
- A stand-by watch is posted outside the space, to keep visual and verbal contact with the entrant and to ensure the entrant exits the Confined Space if symptoms of oxygen deficiency are suspected or observed
- The stand-by watch can raise an alarm to call a trained rescue team by telephone or radio on event of problems
- The rescue team should have been warned of the confined space entry work in progress, and be ready with Self Contained Breathing Apparatus (SCBA) and other equipment so that they can safely enter the Confined space to go to the assistance of, or to extract the victim if necessary.
- The stand-by watch should never enter the Confined Space.
- Plans have been made to obtain treatment/assessment from qualified medical personnel for the victim as soon as possible after he is retrieved from the room.



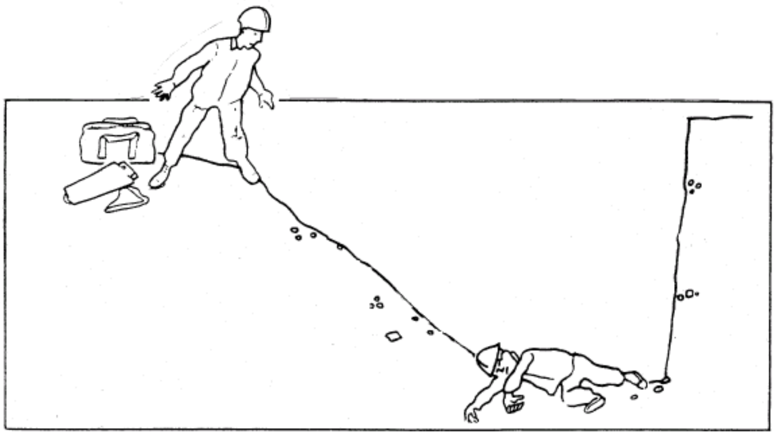


Unplanned Rescue Scenario:
All Confined Spaces shall be closed or barricaded to prevent unauthorised access. There should be no possibility for uncontrolled entry into the Confined Space, so the "unplanned rescue" situation should not occur!

If however a person is found collapsed in a Confined Space where there is a potential inert gas / oxygen deficient atmosphere, then the discoverer must assume that **his life is at risk** entering the same area. He must raise an alarm and call for assistance so that a prepared rescue can be carried out.

IF the victim has collapsed as a result of an oxygen deficient atmosphere and been there for any length of time it is very likely that he is dead and the discoverer's life is risked in vain.

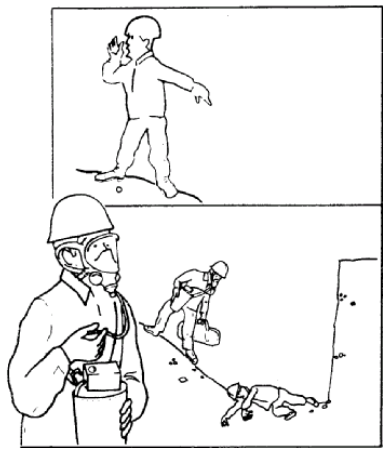
Appendix B3: Rescue considerations from pits, trenches

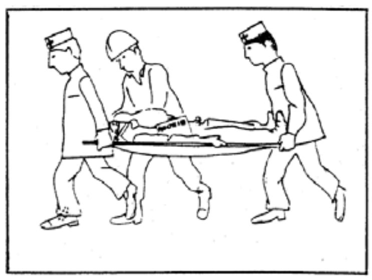


Planned Rescue Scenario:

If work is undertaken in an **excavation, trench, pit**, or other open spaces with potential inert gas / oxygen deficient atmosphere, it is strongly recommended that:

- The atmosphere within the space is checked before entry
- The entrant carries a personal oxygen monitor, as the oxygen concentration may vary within the space if there is limited fresh air circulation.
- A stand-by watch is posted outside the space, to keep visual and verbal contact with the entrant and to ensure the entrant exits the area unaided if symptoms of oxygen deficiency are suspected or observed.
- The stand-by watch can raise an alarm to call a trained rescue team by telephone or radio on event of problems.
- The stand-by watch has Self Contained Breathing Apparatus (SCBA) ready IF it is practical for him enter the enclosed room to go to the assistance of, or to extract the victim alone. OR
- The rescue team should have been warned of the confined space entry work in progress, and be ready with Self Contained Breathing Apparatus (SCBA) and other equipment so that they can safely enter the space to extract the victim if necessary
- Plans have been made to obtain treatment/assessment from qualified medical personnel for the victim as soon as possible after he is retrieved from the room.





Unplanned Rescue Scenario:
If a person is found collapsed in a trench, pit or other space where there is a potential inert gas leak / oxygen deficient atmosphere, then the discoverer must assume that **his life is at risk** entering the same area. He should raise an alarm and call for assistance so that a prepared rescue can be carried out.

IF the victim has collapsed as a result of an oxygen deficient atmosphere and been there for any length of time it is very likely that he is dead and the discoverer's life is risked in vain.
In addition it will often require several people to remove a victim from these kinds of spaces.

Appendix C: Accidents involving oxygen deficiency

The following list highlights real accidents recorded by EIGA, some of them very recent. The list illustrates how essential it is to regularly draw the attention of our personnel, as well as that of our customers, to the hazards of inert gases and oxygen deficiency.

1. A new pipeline in a trench was being proof tested with nitrogen. A charge hand entered the trench to investigate the cause of an audible leak. He was overcome by nitrogen and died.

2. A workman was overcome by lack of oxygen after entering a large storage tank, which had been inerted with nitrogen. Two of his workmates, who went to his aid, without wearing breathing equipment, were also overcome and all three died.

3. A man was overcome on entering a steel tank which had been shut up for several years. The atmosphere inside the tank was no longer capable of supporting life due to removal of oxygen from the air by the rusting of steel.

4. A worker from a contractor company had to carry out welds inside a vessel. The vessel had been under a nitrogen blanket, but was ventilated with air before work started. In order to be on the safe side, the welder was asked to wear a fresh air breathing mask. Unfortunately a fellow worker connected the hose to a nitrogen line and the welder died from asphyxiation.

   This accident happened because the nitrogen outlet point was not labelled and had a normal air hose connection.

5. Welding work with an argon mixture was performed inside a road tanker. During lunchtime the welding torch was left inside the tank, and as the valve was not properly closed, argon escaped. When the welder re-entered the tank, he lost consciousness, but was rescued in time.

   Equipment that is connected to a gas source, except air, must never be left inside confined spaces during lunch breaks, etc. Merely closing the valves is not a guarantee against an escape of gas. If any work with inert gas is carried out in vessels, etc. take care with adequate ventilation or the use of proper breathing equipment.

6. A driver of a small-scale liquid nitrogen delivery service vehicle was making a delivery. He connected his transfer hose to the customer-installed tank, which was situated in a semi-basement. After he had started to fill, one of the customer's employees told him that a cloud of vapour was forming around the tank. The driver stopped the filling operation and returned to the area of the tank to investigate. On reaching the bottom of the stairs, he collapsed, but fortunately he was seen by one of the customer's staff that managed to put on breathing apparatus, go in and drag the man to safety. The driver fully recovered.

   Unknown to the driver, the bursting disc of the storage tank had failed prior to the start of his fill and as soon as he started filling, nitrogen escaped in the vicinity of the storage tank. The oxygen deficient atmosphere overcame him when he went down to investigate without wearing his portable oxygen monitor, which would have warned him of the oxygen deficiency. The installation had been condemned and was no longer being used. Not only was the tank situated in a semi-basement, but the relief device was also not piped to a safe area.

7. During a routine overhaul of an air separation plant, a maintenance technician had the task of changing the filter element on a liquid oxygen filter. The plant was shut down and a work permit was issued each day for each element of work. In spite of these precautions, the technician collapsed when he inadvertently worked on the filter after it had been purged with nitrogen. The fitter collapsed apparently asphyxiated by nitrogen. All efforts to revive him failed.

8. At a cryogenic application, the equipment pressure relief valve located on the equipment **inside** the building opened because the pressure in the storage tank **outside** increased above the setting of the equipment pressure relief valve. Personnel about to enter the room the next morning were warned by the frosted appearance and did not enter.

9. A customer was supplied with 2 low temperature-grinding machines, which were located in the same area in the factory. The customer installed a joint nitrogen extraction system between the two machines. One machine was switched off for cleaning while the other machine was left running. One of the operators who had entered the unit for cleaning fell unconscious and was asphyxiated before help arrived. The linked extraction system had allowed exhausted nitrogen from the operating machine to flow into the unit to be cleaned.

10. A driver was fatally asphyxiated during commissioning of a nitrogen customer station. The customer station tank was located in a pit that was not recognized as a confined space by the design team, distribution operation team or the driver. The driver was sent to do the commissioning by himself.
    During the commissioning the driver made a mistake in opening the liquid supply line valve, instead of the gas vent valve, for purging and cool down of the tank. It is believed he did not immediately notice the valving error partially due to a modified manifold that allowed gas to vent from an uncapped drain in the liquid supply line. When the driver opened the valve gas started venting as would normally occur except from the wrong location. Once he noticed that liquid rather than gas venting, he went into the pit to correct the valving error. At this point he walked into a nitrogen rich/oxygen deficient atmosphere.

11. A group of workers were routinely working at the in-feed end of a tunnel freezer. As the temperature of the tunnel was approaching the desired set point, a new operator noticed that there was a cloud of N_2 gas coming out at exit end of the freezer. He suddenly increased the speed of the scroll fan in order to remove the gas from exit to product entrance. The exhaust and scroll fans were running on manual mode. As a result, the N_2 cloud moved to product entrance and five workers who were working around the loading table passed out. Fortunately, there were no serious injuries and all of them returned to work after taking a rest.

12. On an ASU still in commissioning phase three painters from a sub-subcontractor were working on a ladder to complete external painting works on nitrogen/water tower. To complete the painting of top tower section a wooden plank was put across the exhaust section to atmosphere. One painter climbed on the plank, surrounded by the nitrogen stream, and fell off inside the tower. The two other painters rushed from the ladder to the plank to rescue their team mate. Both collapsed into the tower as well. The three painters died before they could be rescued.

13. An experienced contractor was used to purge a natural gas pipeline, 0.5m diameter 10 km long, with nitrogen before start-up. When one contractor employee and two customer employees entered the remotely located chamber, they were asphyxiated and later found dead in the chamber. Two blind flanges were leaking and the oxygen monitor was not used.

14. A customer nitrogen tank, volume 10 m^3, on a PSA plant was to be inspected by the competent body. The inspector entered the tank and lost consciousness immediately. Two persons from the gas company participating in the inspection managed to bring the inspector out without entering the tank. The inspector recovered.

15. A liquid CO_2 tank was installed. The tank should be purged with air but mistakenly the hose was connected to nitrogen. The tank manhole was situated 4 m above ground. For reasons unknown, a contract employee brought a ladder, entered the tank and was asphyxiated. Previously that morning employees had been told not to enter the tank before the atmosphere was officially checked.

16. Employee stepped into a control cubicle where the instrument air was temporarily replaced with N2 during shutdown. The green light outside the door was on indicating safe atmosphere. As soon as he stepped into the cubicle his personal O_2 monitor alarmed indicating 18% O_2 or less. After exiting safely he opened the door and when O_2 level was OK, checked the fan. The ventilation fan was not running. The light was wrongly wired.

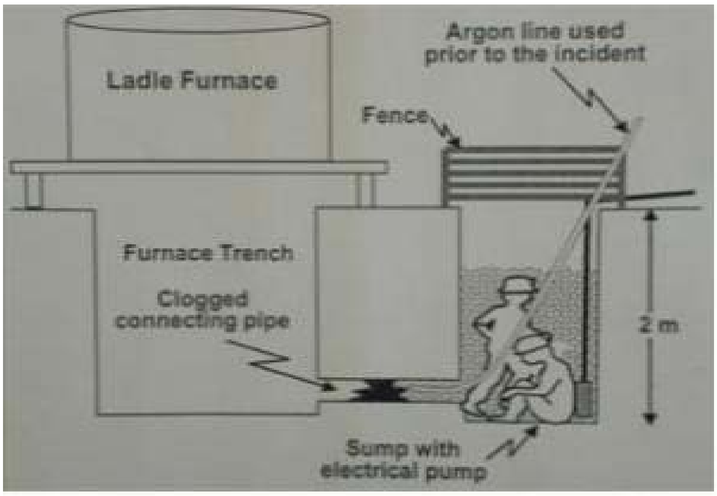
17. The perlite in a storage tank under erection had to be emptied by a contractor company, familiar with this job. During this work one of the workers fell down in the perlite, depth approximately 3m, and was asphyxiated.

18. During the cleaning and painting maintenance of the internal and external surfaces of a water tank, one operator suffered anoxia due to nitrogen being used to purge the vessel instead of air. Two employees tried to rescue the victim and fainted. These two operators were rescued and transported to hospital for intensive care however the original operator died.

19. During the installation of a new LIN phase separator on LIN pipe work at a customer site, a technician went into the roof space. His personal oxygen-monitoring device began to alarm immediately, indicating low oxygen levels. The technician left the roof space immediately and informed the customer. Later in the same week, the customer owned food-freezing machinery was operating, and a project engineer measured concentrations far below 19% in the production room. He left the room, asked all subcontractors to stop work and leave the room, and informed the customer. Investigation showed that the customer had not connected the exhaust ducting to the food-freezing machine that they owned and installed. The exhaust pipes ended in the attic space, not being extended to the atmosphere. Customer had "bridged" the alarm/trip output so LIN supply would not be shut off by low O_2 concentrations.

20. An experienced site employee wanted to take some photographs to add to a report concerning production problems relating to problems with leaks in the argon condenser. In the control room he asked a Contractor to accompany him to take photographs of equipment in the cold box. One hour later the two men were found unconscious in a manhole access to the cold box. Emergency authorities were called and declared the two men dead.

21. Two people on a customer‘s site were asphyxiated and died whilst attempting to unblock a pipe, using Argon gas in a confined space. The use of Argon gas in this application is not authorised. The incident took place in a sump 2 metres below ground level, which is used to drain water from a nearby trench.



22. An air compressor that provided instrument air to an acetylene plant and for breathing air failed. A back-up nitrogen supply from a liquid cylinder was connected to the piping system to replace the function of the air compressor. An operator put on a full respiratory face mask to load Calcium Carbide into the hopper and inhaled nitrogen. He died.

Appendix D: Hazard of inert gases sign

DANGER OF DEATH

Potential Asphyxiating Atmosphere