DISPOSAL OF GASES

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As part of a programme of harmonisation of industry standards, the European Industrial Gases Association (EIGA) has published EIGA Doc 30, *Disposal of Gases*. This publication was jointly produced by members of the International Harmonisation Council.

This publication is intended as an international harmonised publication for the worldwide use and application by all members of the International Harmonisation Council whose members include the Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), European Industrial Gases Association (EIGA), and Japan Industrial and Medical Gases Association (JIMGA). Regional editions have the same technical content as the EIGA edition, however, there are editorial changes primarily in formatting, units used and spelling. Regional regulatory requirements are those that apply to Europe.

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Amendments to 30/13

Section	Change
Terminology	The terms "absorption / adsorption / reaction" have been clarified.
Previous par. 5	The previous paragraph with gas characteristics has been removed as current regulatory information (classification and labeling) is available in the SDS.
5	Schematic arrangement of disposal methods: Drawings have been standardized and completed.
7.3	Indication by colour has been changed to indication by valve outlet connection, pressure relief device and/or valve type.
8.5	The paragraph on hazardous residues has been extended with an additional section (8.5.1) about the hazards of diborane, diborane mixtures and pentaborane.
8.5.1.1	Removal of ACGIH reference
Annex I	The annex has been renamed Annex A and is completely updated. New gases have been added as well as CAS Registry Numbers to ease identification. Disposal methods, key characteristics and operational and safety considerations have been made more consistent.
Previous Annex II	This annex with index to gas names and synonyms has been removed as the data is available from other sources.

NOTE Technical changes from the previous edition are underlined

1 Scope and purpose

1.1 Scope

This publication recommends disposal methods for more than 140 gases and their mixtures and provides safe practices for the disposal of their containers when unserviceable. This publication reflects the concern of the industrial gases industry to ensure that when the need arises for disposal of gases and mixtures, standards of health, safety, and environmental quality continue to be maintained. Only environmentally acceptable methods are proposed.

The principles, recommendations, and requirements in this publication may be applied to both routine and emergency disposal operations; however, emergency disposal operations may dictate special or one of a kind procedures.

1.2 Purpose

Dealing with damaged and / or unidentifiable containers (gas cylinders, drum tanks, and similar transportable and pressurised vessels) is often an integral part of the gas disposal operation, and for this reason guidance on the subject is included. However, such work is potentially dangerous and shall only be performed by experienced and competent personnel following a risk assessment.

This publication should be used as an aid in the training of operators involved in the disposal of gases. The sections have been written with this in mind, and in particular summary checklists have been added for use as training modules.

It is the responsibility of the owner of the gas containers to dispose of the gas container in due time before they cause additional risks for the personnel in charge of the disposal and / or the environment.

1.3 Key operations for safe remediation and / or disposal of contents and / or containers

Key operations may include:

- Identify container contents, see Section 7;
- Select disposal method, see Section 5;
- Safely dispose of container contents, see Section 6;
- Evacuate and / or purge container, see 8.3;
- De-valve container, see 8.4;
- Remove any noxious residues from the container, see 8.5; and
- Render container unserviceable and scrap, see 8.6.

NOTE If doubt exists at any stage in the procedure, specialist advice should be obtained.

2 Definitions

For the purpose of this publication, the following definitions apply.

2.1 Publication terminology

2.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

2.1.2 Should

Indicates that a procedure is recommended.

2.1.3 May

Indicates that the procedure is optional.

2.1.4 Will

Is used only to indicate the future, not a degree of requirement.

2.1.5 Can

Indicates a possibility or ability.

3 Training and safety in the disposal of gases

3.1 Training

It is essential that all personnel engaged in the disposal of gases shall be properly trained and equipped and their practical competence established before they engage in disposal work. In specific cases, local certification may be required.

In some instances, the emphasis is on using experienced operators and it is important to understand that this publication assumes that the operator's experience has also been reinforced with systematic and recorded training.

All operators undertaking gas disposal work shall:

- be properly trained in practice and theory;
- have written instructions / checklists;
- be properly equipped with personal protective equipment (PPE); and
- be provided with correctly designed disposal plant and equipment, and, if expected to deal with emergency situations, be trained to assemble emergency rigs from readily available materials.

3.2 Training procedure

Training shall be based on written instructions and procedures including checklists and shall be carried out by a competent person. The training programme shall be a blend of theory and practice, and each phase of training shall be recorded and signed off on completion, by both the trainer and the trainee. Refresher training at predetermined intervals should also be given.

3.3 Training scope

The training programme should include:

- product and container knowledge, including identification of contents;
- knowledge of standard valve outlet connections, valve types, and pressure relief devices (PRDs), and their applications;
- principles of disposal method selection;
- disposal procedures;

- basic understanding of applicable regulatory requirements for disposal of contents;
- personal protection and general safety; and
- risk assessment.

3.3.1 Product knowledge

The training programme should provide operators with:

- understanding of the general properties of gases; and
- more detailed understanding of the physical and chemical properties of the specific gases they are handling, and particularly their hazardous properties.

The safety data sheets (SDS) shall be available and used during the training.

3.3.2 Container knowledge

Training should include:

- basic knowledge of the containers and how to handle them safely;
- key features of valve design and the purpose of any safety devices fitted;
- identification of cylinder contents.

3.3.3 Selection of disposal method

Even where operators have the disposal method prescribed, it is recommended that they understand the disposal options and the principles of selecting an appropriate disposal method.

3.3.4 Operation of disposal plant / equipment

Training shall be carried out in conjunction with written procedures that shall include coverage of all foreseeable / potential hazards.

Safe handling methods of any chemical reagents and the disposal of any resultant spent chemicals or by-products should also be included.

Emergency procedures in the event of spillage, leak, fire, etc., should be considered, documented, and practised.

3.3.5 Personnel safety

For training in personnel safety to be effective it shall be supported by written, clear, practical, and authoritative rules on the use of personal protective equipment (PPE).

PPE likely to be covered in the training are:

- eye and face protection;
- breathing equipment;
- head protection;
- body protection (chemical resistant and or flame retardant clothing, safety shoes, gloves);

- hearing protection;
- gas monitors; and
- any other PPE that could be required to handle the materials.

The operator shall also be trained in the understanding and use of installed safety features such as special ventilation systems, fire prevention / firefighting equipment, and gas monitoring systems.

3.4 Safety—Design of plant and equipment

Proper design of plant and equipment is a prerequisite for safe operation.

Key features to check are:

- design shall be carried out by a competent person and should be checked by someone other than the designer;
- risk assessment shall be carried out including routing disposal operations;
- all pipes and vessels shall be designed to contain any pressure likely to be experienced and the design and working pressures should be known by the operator; and
- all materials used shall be compatible with the gases to be dealt with.

3.5 Safety checklist

- Are the methods and procedures written down and approved;
- Are the intended disposal processes and the gases covered by the site operating permit;
- Are the written procedures available in the working area;
- Has the equipment been properly designed particularly for materials compatibility and pressure;
- Are adequate warning notices displayed and is the area restricted to authorised personnel;
- Are emergency procedures prepared and understood;
- Has the operator been formally trained and has the training been documented;
- Does the operator have the correct PPE and been trained to use it;
- Should breathing apparatus be available? If yes, is it functioning correctly, properly located, and is the operator trained to use it;
- Are trained first responders and first aid equipment available;
- Have adequate preparations been made for treatment of persons exposed to the gases being handled;
- Have adequate preparations been made for decontamination of persons and equipment exposed to the gases being handled;
- If highly toxic and / or corrosive gases requiring specialist medical treatment are being handled, have the local medical services been informed;
- Are medical treatment protocols available for the products being disposed;

- Is the SDS available for the product to be disposed;
- Is the disposal system capable of handling the quantity and type of gases to be treated; and
- Are spent chemicals appropriately segregated and disposed of according to their properties.

Operators shall not put gases for disposal into the disposal system without first establishing the compatibility of the gas with the disposal system and the capacity and performance of the system. A waste basket approach is prohibited on grounds of safety.

4 Selection of disposal method [1, 2, 3] [1]

4.1 Introduction

There are many disposal methods available. It is the responsibility of a competent person to select an appropriate method for the condition that exists. In the absence of a specific procedure, the selection of an appropriate method shall be based on a risk assessment.

It is important when disposing of a gas that new safety problems are not created. For example, it is of little value to dispose of a gas by burning if the products of combustion sent to the atmosphere are just as toxic as or more than the gas being treated. Nor is it helpful if the disposal of a gas by scrubbing results in a chemical equally as toxic and difficult to get rid of as the original gas.

There are four principal methods of disposal listed by order of preference:

- recycling;
- absorption / adsorption / reaction;
- burning or incineration; and
- venting to the atmosphere.

These methods are further detailed and described in Section 5.

In Appendix A, recommendations are made for the methods of disposal of all gases listed. When selecting a method, there are three important considerations:

- characteristics of the gas being treated;
- local conditions, regulatory requirements, and operational constraints; and
- quantity of gas to be disposed.

For most gases, several methods are recommended. The person responsible for the disposal operation shall select a method and prepare instructions taking local conditions, regulatory requirements, and operational constraints into account. When designing equipment and selecting disposal methods, due care and attention should be exercised.

Venting to the atmosphere by dilution should be avoided for gases that cannot be vented in pure form because of environmental considerations.

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[1] References are shown by bracketed numbers and are listed in order of appearance in the reference section.

4.2 Gas characteristics

It is essential that the operator be fully aware of the main characteristics of the gases being disposed. Of particular importance is if they are toxic, flammable, oxidising, harmful, or corrosive. Each of these characteristics can dictate which methods of disposal are practical and effective.

Other characteristics that need to be known are whether the gases have any warning properties by smell or sight, what materials they are compatible with and which materials are prohibited, whether the gases are liquefiable or permanent, and the possible reactions with the atmosphere.

Information on the physical properties is also important. Density of the gas relative to air, boiling point, and vapour pressure should be known when dealing with liquefied gas.

Because certain key gas characteristics are so important to the disposal operation, they have been listed in in Appendix A. More information on the gases shall be obtained from the SDS of the suppliers and from the publications referenced in Section 9.

4.3 Local conditions, regulatory requirements, and operational constraints

While the fundamental requirement not to damage the environment is of overriding importance, it shall still be acknowledged that local conditions can affect the choice of method used. Where disposal has to take place in the midst of other activities, the precautions may be more stringent than when disposal is carried out in an open and isolated region. In the former case, weather conditions can also play a part. Precautions may have to be taken when windless and inversion conditions prevail.

This publication has tried to take into account legislation / regulation; however, it is the responsibility of the operator to ensure awareness of and compliance with all regulations and legislation applicable to the location.

4.4 Quantity of gas

Quantity of gas to be disposed of is an important consideration when designing and operating the system. The system shall be operated so the quantity of gas being disposed of shall not exceed system capacity.

4.5 Disposal checklist

Considerations when choosing method of disposal:

Gas characteristics	Local conditions and constraints	Quantity (kg)
Toxic Flammable Oxidant Corrosive Pyrophoric Harmful to the environment Warning properties Pressure / vapour pressure Liquefiable / compressed Boiling point Density relative to air Compatible materials Combination of the previous characteristics	Available space Other activities in vicinity Weather conditions Availability of expertise and equipment Condition of container and valve Legislation / regulation	Small Medium Large

5 Methods of disposal [1, 2]

5.1 Introduction

This section describes the basic principles of the four disposal methods:

- recycling;
- absorption / adsorption / reaction;
- burning or incineration; and
- venting to the atmosphere.

In the case of mixtures, more than one method can be necessary. Recovery and recycling of the gases should be considered in all cases provided it is safe to do so.

Each disposal method is named and detailed under the following headings:

- illustrative example of the disposal method;
- description of method;
- application;
- equipment design;
- operation; and
- operational precautions.

5.2 Index to methods

Method	Section
Method 1 Recycling of gases	5.3.1
Method 2 Disposal of gases by absorption / adsorption / reaction	
2A—Direct discharge into simple scrubber	5.3.2.1
2B—Discharge into counterflow scrubber	5.3.2.2
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Method 3 Disposal of gases by burning or incineration	
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3B—Combustion / incineration (liquid phase)	5.3.3.2
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Method 4 Disposal of gases by venting to the atmosphere	
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4B—Direct discharge from container valve into fume cubicle or hood	5.3.4.2
4C—Controlled release through vent line	5.3.4.3
4D—Controlled dilution in forced air stream	5.3.4.4

5.3 Methods

Do not dispose of flammable or oxidant gases as mixed batches of cylinders.

5.3.1 Method 1—Recycling of gases

General principles—This is not a disposal method, as usually understood, but a technique for reclaiming residual gases and returning them safely to suitable containers for re-use.

As a solution to dealing with residual gases, it is strongly recommended both in the interests of the environment and the conservation of materials and energy. Recycling is a particularly favoured technique when dealing with high value gases, or gases that are expensive to dispose of due to their nature or because of the quantity involved. Most recovered product may have to be reprocessed and purified before being re-used, and the cost of such treatment should be taken into account when considering a recycling system.

It shall be stressed that recycling of gases is best carried out by the supplier of the material who has the necessary product handling and container filling expertise. Material shall not be returned to a container without the written authority of the owner of the container. The owner shall specify, or have agreed to, the method, equipment, and procedures to be used.

Different transfer methods can be used. Liquefiable gases can be transferred to the recovery container in the liquid phase either by pressurising the container to be emptied with a compatible inert gas, by pumping, or by creating a vapour pressure gradient.

Gases can be recompressed into the recovery container using a gas compressor or by liquefying the gas cryogenically into a suitable cryogenic receiver. It is important to ensure that any carbon steel container or pipework is not used in contact with cryogenic liquids as they can become brittle at temperatures less than –20 °C (–4 °F). The cryogenic liquid is then allowed to warm and the resultant gas passed into the recovery container [4, 5].

When recycling gases, care shall be taken to ensure that the product to be recycled is not contaminated with any material that could have a detrimental effect on the safety of the operation or subsequent use of the recycled material. Care shall be taken when recovering liquefied gases that the recovery vessel will not be overfilled or exceed the ADR filling ratio. For gases that can polymerise or that can decompose, ensure that the product is pure, stable, or contains sufficient amount of stabiliser.

5.3.2 Method 2—Disposal of gases by absorption / adsorption / reaction

General principles—Disposal of certain reactive gases can be achieved by absorption / reaction in a liquid (scrubbing) or by adsorption in a solid-state medium. The resultant solution and / or suspension or other absorption product should be less harmful and more conveniently disposed of than the original gas.

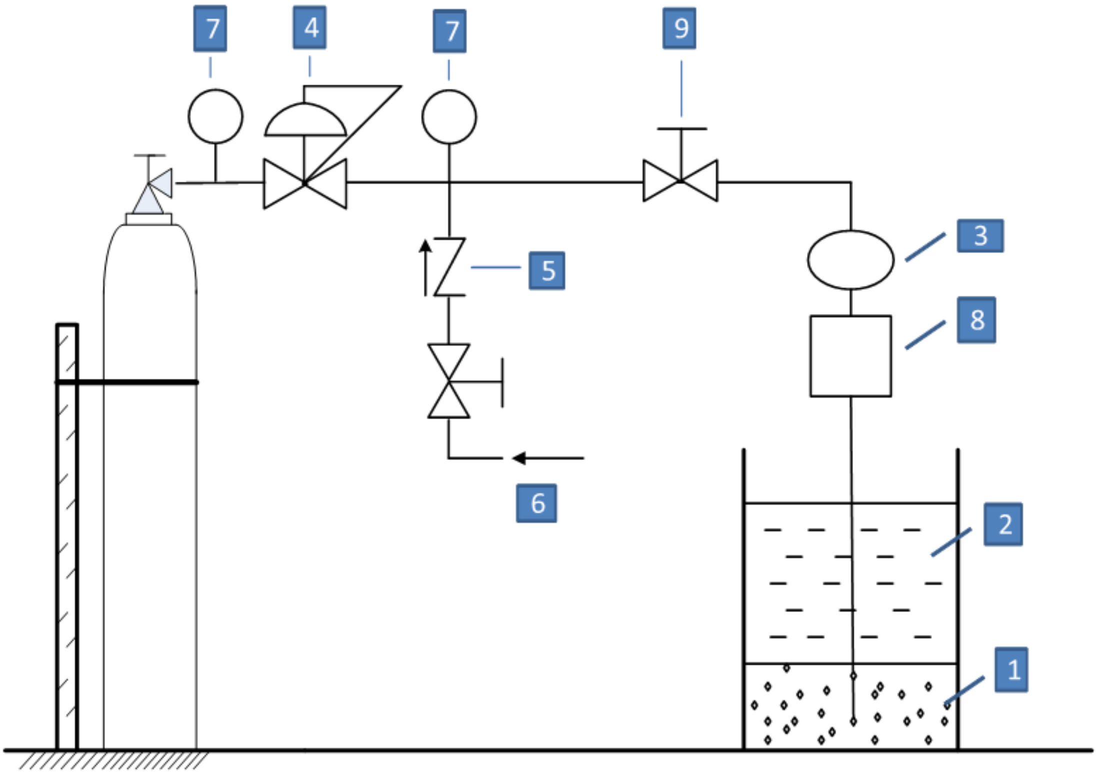
This method can be used in conjunction with methods where harmful combustion products are evolved.

The choice of absorption / adsorption reagent medium and equipment used depends on a number of factors including:

- reactivity of the absorption / adsorption medium with the gas;
- quantity of gas to be disposed of and frequency of disposal operations; and
- ease of treatment of the spent absorption / adsorption medium.

These factors shall be considered when selecting absorption / adsorption reagent medium and method.

5.3.2.1 Method 2A—Direct discharge into simple scrubber



1. Packing medium (shingle)
2. Absorbent chemical (reacting chemical)
3. Sight glass/ rotometer (optional)
4. Pressure control valve
5. Non-return valve
6. Inlet gas purge (optional)
7. Pressure indicator
8. Suckback trap
9. Flow control valve (needle valve)

NOTE—This is an illustrative example and not intended for design.

Figure 1—Method 2A: Direct discharge into simple scrubber

5.3.2.1.1 Description of method

The gas to be disposed of is fed directly into the absorbent chemical. Under certain circumstances, liquefied gas can be fed into the scrubber in the liquid phase following a risk assessment.

5.3.2.1.2 Application

This method is recommended where absorbent chemical is available that strongly and readily absorbs the gas or reacts with it. Simplicity and portability can favour the choice of this method under emergency conditions. This method should be restricted to gases that are not acute toxic category 1 ($LC50_{rat.1h} < 200$ppm) or acute toxic category 2 ($LC50_{rat.1h} < 1000$ppm) nor carcinogenic, mutagenic, or reprotoxic because of the risk of exposure to the release of non-reacted toxic gas.

5.3.2.1.3 Equipment design

Equipment should be kept as simple as possible, should be suitable for the required working pressure, and compatible with the gas and the absorbent chemical. It is desirable to maximise the contact of the gas with the absorbent chemical. This can be achieved by constricting the end of the pipe dipping into the absorbent chemical (to reduce the gas bubble size) and / or by submerging the pipe in a layer of coarse sand at the bottom of the scrubber vessel.

A flow control system (incorporating a pressure regulator, if necessary) should be installed in the gas feed to enable the gas flow to be matched to the capacity of the scrubber or by use of a sparger.

A suckback trap or a vacuum breaker should be incorporated in the line before the scrubber pot. A sight glass or length of transparent pipe may also be installed between the regulated gas supply and scrubber to indicate suckback conditions. A continuous inert gas purge also reduces the risk of suck back.

5.3.2.1.4 Operation

a) Purge air from the system with an inert gas if the gas or gas mixture is flammable;

b) Check that the flow control valve is closed;

c) Open the gas supply valve and adjust pressure regulator as appropriate (if fitted);

d) Slowly open the flow control valve until the scrubber capacity is achieved (i.e., maximum flow rate compatible with complete gas absorption);

e) Renew the absorbent chemical as necessary. Dispose of spent scrubber chemical safely according to legislation / regulation; and

f) When the disposal operation is complete (or when renewing absorbent chemical), close the gas supply valve. Purge the system with inert gas (where installed) and close the flow control valve.

5.3.2.1.5 Operational precautions

This operation should be carried out in a well ventilated or open area.

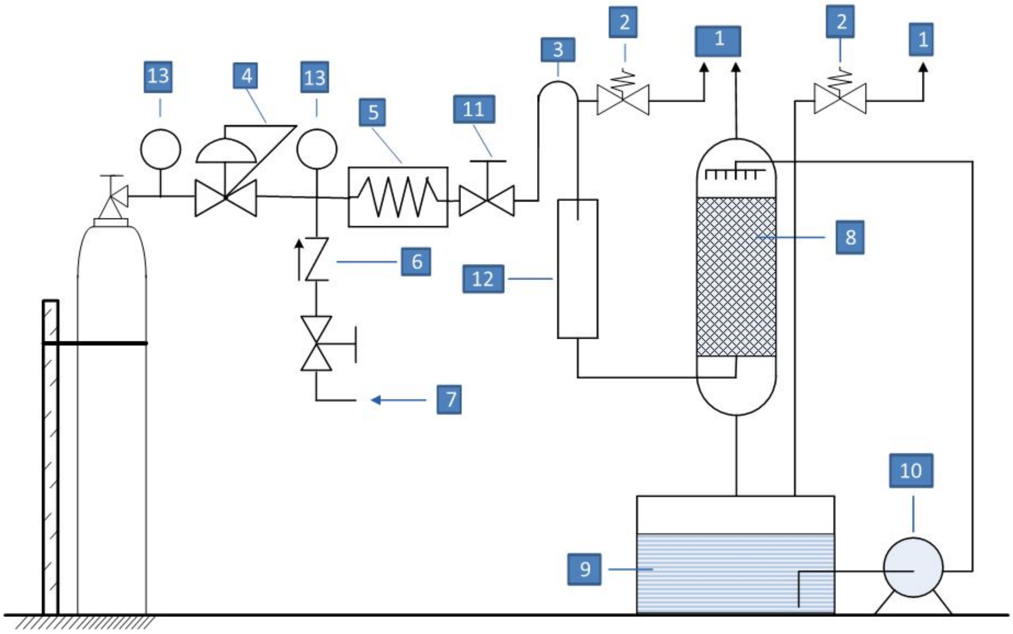
Ensure that the absorption / reaction is taking place effectively and safely throughout the disposal operation. Constant vigilance is necessary to ensure no blockage, breakthrough, overheating, or chemical suck back occurs.

Particular attention shall be paid to personal protection when handling reactive absorbent chemicals such as caustic or acids.

Ignition sources (including open flames, electrical equipment, static discharge) should be excluded if the gas is flammable or if flammable gases can be produced. Care should be taken to avoid build-up of potentially explosive flammable gas / air mixtures in and around the system. The temperature of the chemical should be checked to avoid a hazardous situation arising. The capacity of the absorption / reaction vessel and the quantity of chemical shall be sufficient to absorb all of the gas to be discharged.

<u>After concluding disposal operations, all equipment should be decontaminated and / or neutralised. Equipment shall be maintained as many gases can be damaging to equipment.</u>

5.3.2.2 Method 2B—Discharge into counterflow scrubber



1. Vent to a safe place
2. Pressure relief valve (if required)
3. Barometric leg
4. Pressure control valve
5. Vaporiser (if required)
6. Non-return valve
7. Inert gas purge (if required)
8. Inert packing
9. Absorbent chemical (reacting chemical
10. Pump
11. Flow control valve (needle valve)
12. Suckback trap
13. Pressure indicator

NOTE—This is an illustrative example and not intended for design.

Figure 2—Method 2B: Discharge into counterflow scrubber

5.3.2.2.1 Description of method

The gas to be disposed of is fed into the counterflow scrubber. The gas can be fed directly as illustrated in Figure 2. The source of gas can also be a fume cubicle or hood (see 5.3.4.2) or an incinerator (see 5.3.3.3). Under certain circumstances, liquefied gas in its liquid phase can be fed into the counterflow scrubber following a risk assessment but note that the pipework configuration shown in Figure 2 is not suitable for this.

5.3.2.2.2 Application

This method is recommended where a suitable absorbent or reacting chemical is available and where there is an ongoing disposal requirement.

5.3.2.2.3 Equipment design

Equipment should be specifically designed by a competent person for its intended service. Materials of construction should be compatible with the gas and absorbent chemical. Due account should be taken of operating pressures and possible temperature rises from reaction between the gas and absorbent chemical. Pumping alkaline absorbents present special problems. Pumps may have to be running continuously to prevent the shaft sticking to pump housing.

Suitable arrangements should be made to ensure the system is monitored and shut down in the event of gas breakthrough. To ensure safe and efficient performance, consideration should be given to monitoring the following:

- gas input flow;
- efficacy of absorbent chemical (for example, pH);
- concentration of gas in scrubber vent; and
- temperature of absorbent chemical.

A barometric leg should be installed in the supply line to the scrubber to minimise the risk of absorbent chemical sucking back.

Consideration can also be given to the provision of an anti-suckback device such as a liquid interceptor vessel fitted with level switch actuating a solenoid valve.

A flow control system (incorporating a pressure regulator if necessary) should be installed in the gas feed to enable the gas flow to be matched to the capacity of the scrubber.

An inert gas purge facility should be installed.

The scrubber vent should discharge to a safe well ventilated place away from personnel.

Consideration should be given to area electrical classification where gas is flammable [6, 7].

5.3.2.2.4 Operation

a) Check scrubber unit is operating correctly:
    - efficacy of absorbent chemical
    - operation of mechanical units such as recirculating pumps, agitators, fans, etc.
    - operation of monitoring equipment
b) Purge air from the system with an inert gas if the gas or gas mixture is flammable;
c) Adjust the feed rate until specified gas flowrate is achieved;
d) Unless automatic shutdown arrangements are installed, supervise the disposal operation, correcting flowrate, replenishing absorbent chemical, etc., as necessary;
e) When the disposal operation is complete, purge the system with inert gas and close the flow control valve; and
f) Shut down scrubber system and dispose of spent absorbent chemical safely.

5.3.2.2.5 Operational precautions

Ensure that the scrubbing system is operating correctly throughout the disposal operation either by automatic monitors or by personal supervision.

Ensure that as flowrate and quantity are controlled so the scrubber does not overheat and breakthrough does not occur.

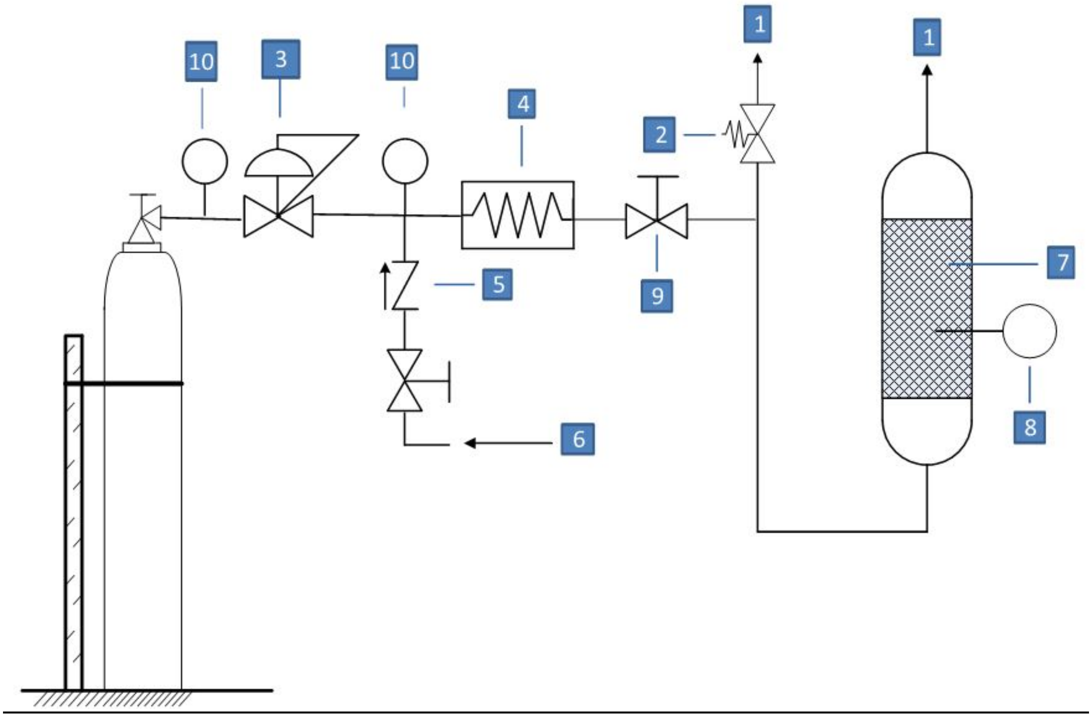
Particular attention shall be paid to personal protection when handling reactive absorbent chemicals such as caustic or acids.

Ignition sources (including open flames, electrical equipment, static discharge) should be excluded if the gas is flammable or if flammable gases can be produced. Care should be taken to avoid build-up of potentially explosive flammable gas / air mixtures in and around the system.

Some gases, especially halogen acid forming gases, form a mist with moist gases that is not readily absorbed by most types of scrubbers. These gases should either be fed to the scrubber in high concentration or diluted with a dry gas to low concentration. The temperature of the chemical (Figure 2, no. 9) or in the scrubber (Figure 2, no. 8) should be checked to avoid a dangerous situation arising. The capacity of absorption / reaction of the absorbent / reacting chemical shall be calculated to be large enough for the quantity of gas to be discharged.

After concluding disposal operations, all equipment should be decontaminated and / or neutralised. Equipment shall be maintained as many gases can be damaging to equipment.

5.3.2.3 Method 2C—Discharge into solid-state adsorber



1. Vent to a safe place
2. Pressure relief valve (if required)
3. Pressure control valve
4. Vaporiser (if required)
5. Non-return valve
6. Inlet gas purge
7. Adsorbent
8. Temperature control unit
9. Flow control valve
10. Pressure indicator

NOTE—This is an illustrative example and not intended for design.

Figure 3—Method 2C: Discharge into solid-state adsorber

5.3.2.3.1 Description of method

The gas to be disposed of is fed into a vessel containing a bed of solid-state adsorbent. The gas can be fed directly as illustrated. The source of gas can also be a fume cubicle or hood (see 5.3.4.2) or an incinerator (see 5.3.3.3).

5.3.2.3.2 Application

This method is recommended where a solid adsorbent is available that strongly and readily adsorbs the gas. Simplicity and portability of a small solid-state adsorber can favour the choice of this method under certain emergency conditions.

5.3.2.3.3 Equipment design

Equipment should be constructed from materials compatible with the gas and solid-state adsorbent. Due account should be taken of operating pressures and possible temperature rises from reaction between the gas and adsorbent medium.

Factors to be taken into account when establishing the size of the solid-state adsorber include:

- required disposal rate;
- quantity of gas for disposal; and
- acceptable frequency of changing / regenerating the adsorbent.

These factors will determine the dynamic and static capacity of the chosen adsorbent.

A distribution system should be incorporated in the adsorber to ensure good distribution of the gas in the bed of adsorbent. Poor gas distribution can result in channelling and premature breakthrough.

The adsorbent particle size is an important consideration when establishing the design of a solid-state adsorber. Generally, small particles give a high contact area and hence greater adsorbing efficiency; however, small particle sizes can lead to clogging or high pressure drops and tendency for channelling through the bed.

Provision should be made to monitor the gas input flow and concentration of gas in the adsorber vent. Consideration should also be given to monitoring the temperature of the adsorber and the need for a cooling system.

A flow control system (incorporating a pressure regulator if necessary) should be installed in the gas feed to enable the gas flow to be matched to the capacity of the solid-state adsorber.

An inert gas purge facility should be installed if practicable.

The solid-state adsorber vent should discharge to a safe, well ventilated place away from personnel.

5.3.2.3.4 Operation

a) Purge the system with an inert gas to remove air if the gas or gas mixture is flammable;

b) Check, as far as practicable, that adsorbent is not spent, for example, from the operating log, which records cumulative throughput;

c) Adjust the feed rate until the specified gas flowrate is achieved;

d) Unless automatic shutdown arrangements are installed, supervise the disposal operation, monitor adsorber vent for breakthrough, and adjust flowrate as necessary. When the disposal operation is complete, close the gas supply valve; and

e) Purge the system with inert gas (where installed) and close the flow control valve.

Dispose of or regenerate solid-state adsorbent safely.

5.3.2.3.5 Operational precautions

Ensure that the solid-state adsorber is operating correctly throughout the disposal operation either by automatic monitors or by personal supervision.

Ensure that gas flow rate and quantity are controlled so the scrubber does not overheat and breakthrough does not occur.

Particular attention shall be paid to personal protection when handling reactive solid adsorbents.

Ignition sources (including open flames, electrical equipment, static discharge) should be excluded if the gas is flammable or if flammable gases can be produced. Care should be taken to avoid build-up of potentially explosive flammable gas / air mixtures in and around the system. The temperature in the adsorbent (Figure 3, no. 7) should be checked to avoid a dangerous situation arising. The capacity of adsorption / reaction of the adsorbent (Figure 3, no. 7) shall be calculated to be large enough for the quantity of gas to be discharged.

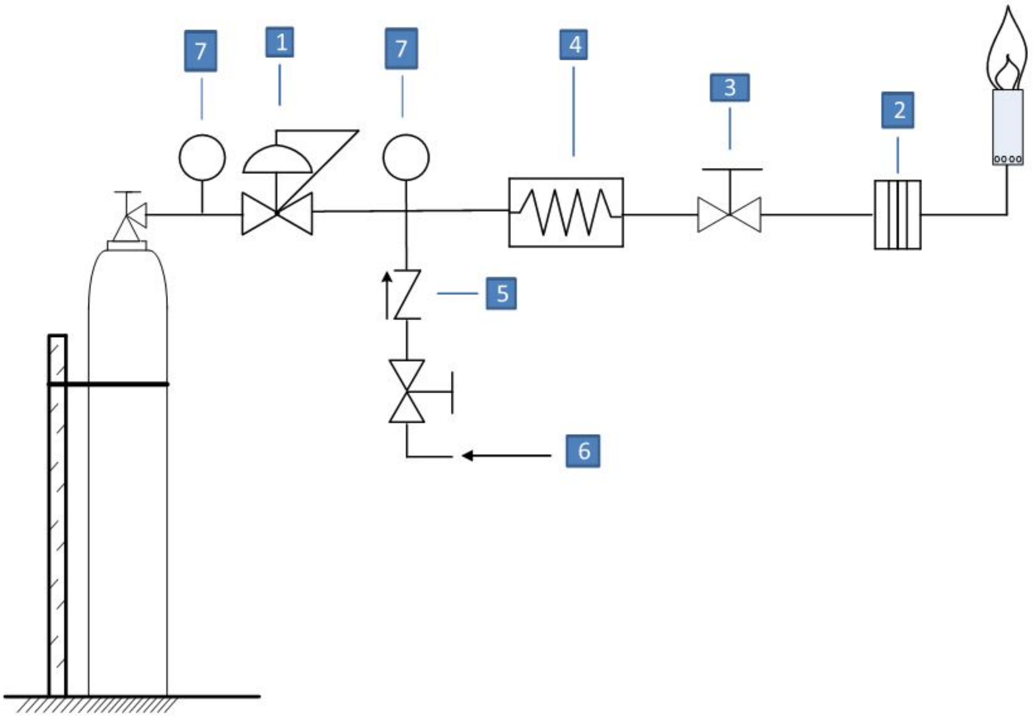
After concluding disposal operations, all equipment should be decontaminated and / or neutralised. Equipment shall be maintained as many gases can be damaging to equipment.

5.3.3 Method 3—Disposal of gases by burning or incineration

General principles—Disposal of certain gases can be achieved by burning or passing through a hot flame. Many flammable gases can burn to form harmless products of combustion. Where toxic products of combustion are formed, these should be dealt with subsequently using one or more of the other methods detailed in this publication.

It is important that flame characteristics are controlled to ensure that the required reaction takes place. It is usually possible to determine flame characteristics by visual observation and / or temperature measurement. Flame control can be achieved by adjustment of the gas flows and / or by addition of an appropriate gas at a controlled rate.

5.3.3.1 Method 3A—Direct combustion (gas phase)



1. Pressure control valve
2. Flame arrestor
3. Flow control valve
4. Vaporiser (if required)
5. Nonreturn valve
6. Inlet gas purge
7. Pressure indicator

NOTE—This is an illustrative example and not intended for design.

Figure 4—Method 3A: Direct combustion (gas phase)

5.3.3.1.1 Description of method

The gas to be disposed of is fed into the burner and burned with an oxidant (usually air).

5.3.3.1.2 Application

This method is recommended for flammable gases that can be burned completely yielding non-toxic products.

5.3.3.1.3 Equipment design

Burner—The fuel gas is usually metered through a jet and mixed with the oxidant prior to burning. The oxidant can be either injected from an external supply under pressure (for example, a welding torch) or drawn into the fuel gas stream by venturi action (for example, a Bunsen burner).

Generally, burners that require addition of an oxidant or fuel under pressure have a wider application range.

Ignition—Ignition can be achieved either manually (matches, flint gun, etc.) or automatically (piezo crystal, hot wire, pilot flame, etc.). Automatic ignition should be used where practical.

Flow controls—Pressure regulators and flow control valves are required to ensure a controlled flame is maintained. Under most circumstances, it is desirable to operate the burner with excess oxidant to minimise the formation of incomplete combustion products such as carbon monoxide.

Purge gas—It is recommended to install a purge gas supply, to clear the system of air before use and of flammable gas after use.

Vaporiser—For the rapid disposal of certain liquefiable gases, product may be withdrawn from the liquid phase (see also 5.3.3.2). Under these circumstances, a vaporiser is usually necessary to ensure only gas is admitted to the burner.

Safety devices—A flame arrestor should be fitted to all fuel lines. Where a vaporiser is installed (for liquefied gases) a PRD could be required. A flame sensor system, which shuts off the gas in the event of flame failure, should be incorporated.

5.3.3.1.4 Operation

a) Purge air from the system with an inert gas to remove air if the gas or gas mixture is flammable;

b) Ensuring fuel gas and oxidant flows are correct, ignite flame;

c) Ensure flame is maintained; and

d) Prior to shut down, purge system with inert purge gas (where installed).

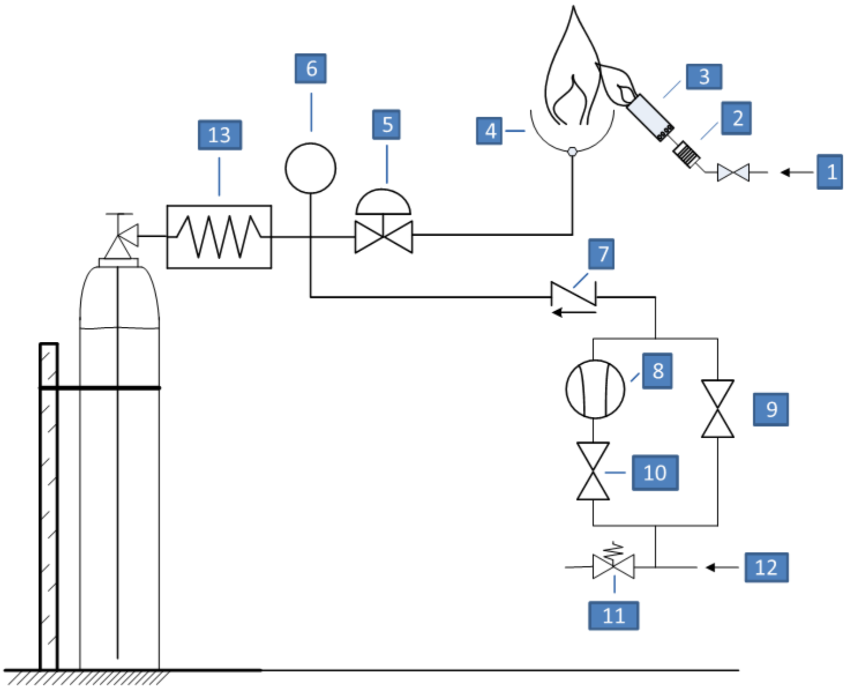
5.3.3.1.5 Operational precautions

Site the burner in a safe position away from combustible material.

Prevent any excessive pressure drop due to the cooling of a liquefied gas being vaporised.

After concluding disposal operations, all equipment should be decontaminated and / or neutralised. Equipment shall be maintained as many gases can be damaging to equipment.

5.3.3.2 Method 3B—Combustion / incineration (liquid phase)



1. Fuel gas	7. Nonreturn valve
2. Flame arrestor	8. Flow indicator
3. Separately fuelled flame	9. Bypass valve
4. Injector nozzle	10. Purge flow control valve
5. Remotely controlled gas valve	11. Inert purge gas
6. Pressure indicator	12. Vaporiser (optional)

NOTE—This is an illustrative example and not intended for design.

Figure 5—Method 3B: Combustion / incineration (liquid phase)

5.3.3.2.1 Description of method

The product is withdrawn from the liquid phase either through a vaporiser or fed as a liquid to the burner and burned in the presence of a separately fuelled flame.

5.3.3.2.2 Application

This method is particularly useful for rapid disposal of liquefiable fuel gases, especially where they have a low vapour pressure or where contamination of solids or low vapour pressure contaminants are suspected.

This method may be extended to include gases that have an oxygen-rich molecule provided a continuous supply of inert gas is added to the product stream during incineration / burning operations.

The presence of a separately fuelled flame can aid incineration of poorly combustible liquefied gases / gas mixtures, for example, 20% ethylene oxide mixtures.

5.3.3.2.3 Equipment design

Injector nozzle—This should be designed to limit the flow of product (without blockage by impurities / combustion products, etc.) to a level that can be safely and completely combusted.

Separately fuelled flame—This should provide a flame of sufficient size, correctly positioned to the injector nozzle, as to ensure complete combustion of the jet of liquid product.

Purge gas—Inert gas for purging the pipe system before and after the disposal operation and for pressurisation of the product container. The purge gas can also be used to assist in the control of the flame by addition to the product stream.

Valve actuation—Remote operation of control valves is recommended. Where this is the case, fail-safe pneumatically operated valves should be used.

5.3.3.2.4 Operation

See also 5.3.2.2.4.

a) Purge air from the system with an inert gas;

b) Position product container to enable liquid withdrawal;

c) It is advantageous (and essential with 100% ethylene oxide, propylene oxide, and similar) to provide an inert gas flow into the product stream during burning; and

d) When all the liquid product has been burned, purge the container of residual gas by repeated pressurisation with the purge gas (check working pressure of container).

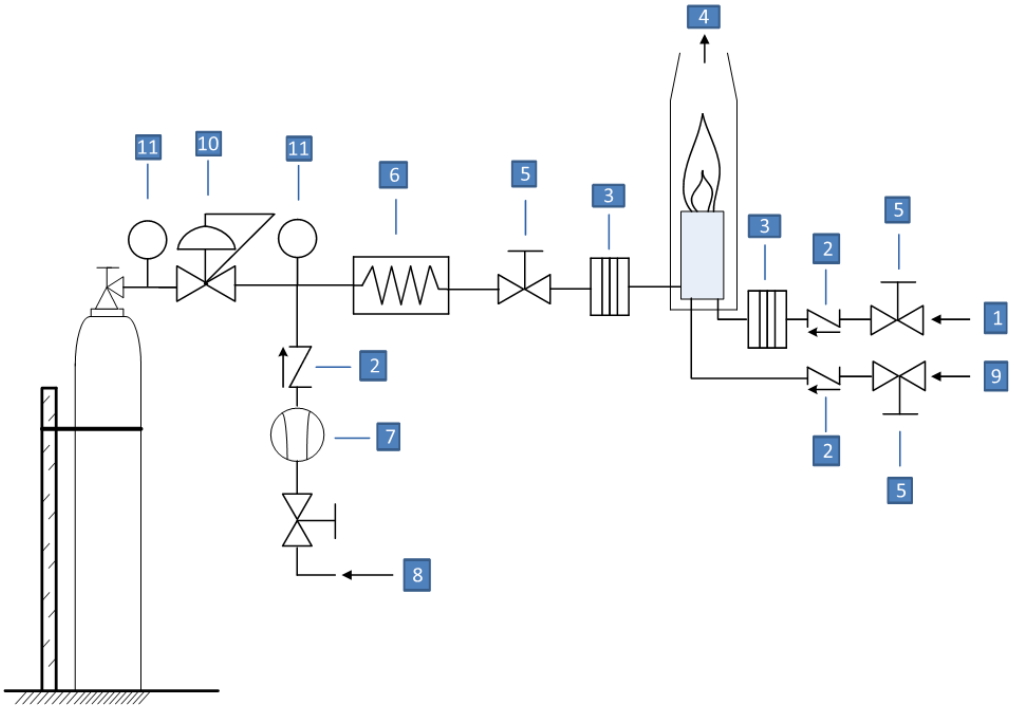
5.3.3.2.5 Operational precautions

Site the burner in a safe position away from combustible materials.

Ensure product container is adequately pressurised with inert gas during the operation.

Observe special precautions when dealing with products such as ethylene oxide. See Appendix A.

5.3.3.3 Method 3C—Incineration (gas phase)



1. Fuel gas
2. Nonreturn valve
3. Flame arrestor (if required)
4. To scrubber unit (if required)
5. Flow control valve
6. Vaporiser (if required)
7. Flow indicator
8. Inlet gas purge
9. Air or oxygen
10. Pressure control valve
11. Pressure indicator

NOTE—This is an illustrative example and not intended for design.

Figure 6—Method 3C: Incineration (gas phase)

5.3.3.3.1 Description of method

The gas is incinerated in a separately fuelled flame.

5.3.3.3.2 Application

This method is particularly useful for the disposal of gases:

- that are non-flammable but can be decomposed in a flame;
- that can be decomposed in a flame but which yield toxic decomposition products that require subsequent treatment; and
- where a carefully controlled burning process is advisable.

5.3.3.3.3 Equipment design

Burner / Separately fuelled ignitor—A suggested design would comprise a burning nozzle with three concentric channels, product flowing through the inner, fuel gas through the middle, and oxidant through the outer channel.

Flow control—Pressure regulators and flow control valves are required to ensure an optimum ratio of fuel gases to oxidant.

Flue gas cooler—If the flue gases will be subject to further treatment, a flue gas cooler can be required to protect from overheating downstream equipment.

Purge gas—It is desirable to install a purge gas supply. The inert purge gas is used to purge air from the gas system prior to introduction of the gas. It may also be used to purge the waste gas container and system at the end of incineration operations.

Vaporiser—A vaporiser can be useful when dealing with low pressure liquefiable gases. Product is withdrawn from the liquid phase and passed through the vaporiser to ensure only gas is admitted to the burner.

Safety devices—A flame arrestor should be fitted to all fuel lines. Where a vaporiser is installed (for liquefied gases) a PRD may be required.

5.3.3.3.4 Operation

a) Purge air from the gas system using inert purge gas;

b) Ignite the separately fuelled flame and adjust;

c) Carefully open the gas supply, observing the flame and increasing the oxidant feed as required by the gas combustion. Optimise the gas combustion but ensure a stable flame is maintained; and

d) To shut down, close the gas supply container valve. Purge the gas system with inert gas (purge gas to pass through the separately fuelled ignitor flame). If empty, the gas container can also be purged an appropriate number of times to dilute its residual contents. Close the oxidant and separate fuel gas supplies. Ensure all flames are extinguished.

5.3.3.3.5 Operational precautions

Site the burner in a safe position away from combustible materials.

Prevent any excessive pressure drop due to the cooling of a liquefied gas being vaporised.

In certain cases, the burning conditions shall be very carefully controlled, otherwise toxic products of combustion formed can be difficult to remove. For example, in the case of ammonia and amines, if oxidant levels are too high, excessive amounts of toxic oxides of nitrogen can be produced. These can prove difficult to scrub.

After concluding disposal operations, all equipment should be decontaminated and / or neutralised. Equipment shall be maintained as many gases can be damaging to equipment.

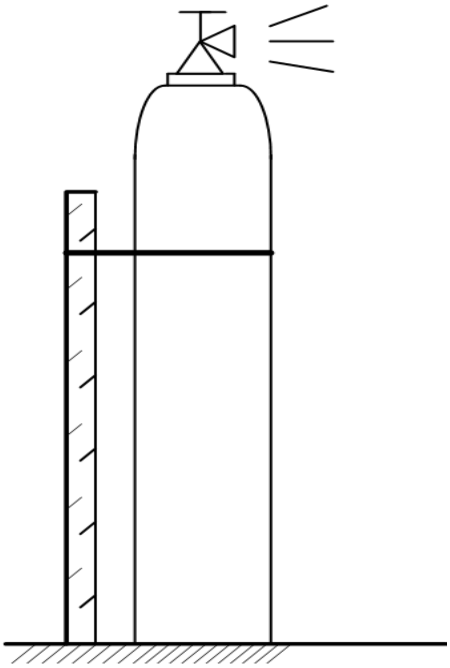
5.3.4 Method 4—Disposal of gases by venting to the atmosphere

General principles—In this method, the gas is diluted with air to a harmless concentration.

This is a most convenient and economical method, but it shall be carried out in a responsible manner to ensure that no hazardous conditions are created, requirements are met, and there is no risk of damage to the environment. As pointed out earlier, venting to the atmosphere by dilution should be avoided for gases that cannot be vented in pure form because of environmental considerations.

Disposal to atmosphere may be direct from the cylinder valve for non-flammable and non-toxic gases, through a vent pipe, or through forced draft ducting.

5.3.4.1 Method 4A—Direct discharge from container valve



NOTE—This is an illustrative example and not intended for design.

Figure 7—Method 4A: Direct discharge from container valve

5.3.4.1.1 Description of method

Gas is discharged directly from the container valve to the atmosphere.

5.3.4.1.2 Application

The method is limited to non-flammable, non-toxic, or non-corrosive gases or mixtures.

5.3.4.1.3 Equipment design

All that is required is a means of opening the container valve. The container should be positively supported.

5.3.4.1.4 Operation

The container valve is opened slowly to permit gas discharge at an appropriate rate.

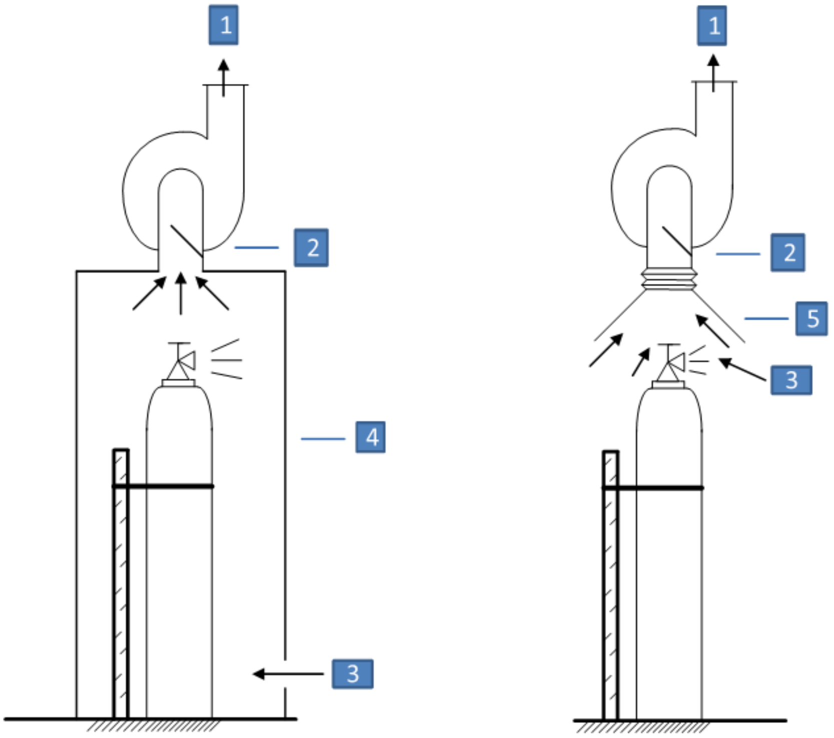
5.3.4.1.5 Operational precautions

The operation should be carried out in a well-ventilated area away from incompatible processes, air intakes, and from persons not engaged in the disposal operation. Gases that have a density heavier than air can collect in low areas or along the ground leading to reduced oxygen content.

Consideration should be given to prevailing meteorological conditions to ensure safe dispersion of vented gases.

Noise level and nuisance odours should be controlled to meet local regulations and site conditions.

5.3.4.2 Method 4B—Direct discharge from container valve into fume cubicle or hood



1. Discharge to a safe place
2. Air flow indicator
3. Air inflow
4. Fume cubicle
5. Fume hood

NOTE—This is an illustrative example and not intended for design.

Figure 8—Method 4B: Direct discharge from container valve into fume cubicle or hood

5.3.4.2.1 Description of method

Gas is discharged directly from the container valve into a fume cubicle or hood. Dilution with air is achieved and the exhaust from the fume cubicle or hood is discharged to a safe place (usually at high level) determined after a risk assessment.

5.3.4.2.2 Application

The method can be used for the disposal of a wide range of gases. It is of high practical value and is widely used. It is particularly useful when dealing with leaking containers or where a disposal operation is required from inside a building.

5.3.4.2.3 Equipment design

A suitable hood to fit over the container valve or a cubicle into which the container can be placed. Air is extracted from the hood or cubicle and discharged to a safe place (usually at high level) away from persons and from incompatible processes and air intakes. The container should be positively supported.

5.3.4.2.4 Operation

a) The container is placed in a fume cubicle or the fume hood is placed over the container valve;

b) The container valve is opened slowly to permit gas discharge at the appropriate rate; and

c) Where a fume cubicle is used, the door(s) or air inlet shall be adjusted to obtain the required air velocity and flowrate for complete gas entrainment

5.3.4.2.5 Operational precautions

If the cylinder content is flammable, only a limited flow of gas shall be disposed of in this way. Ignition sources (including open flames, electrical equipment, static discharge) shall be excluded.

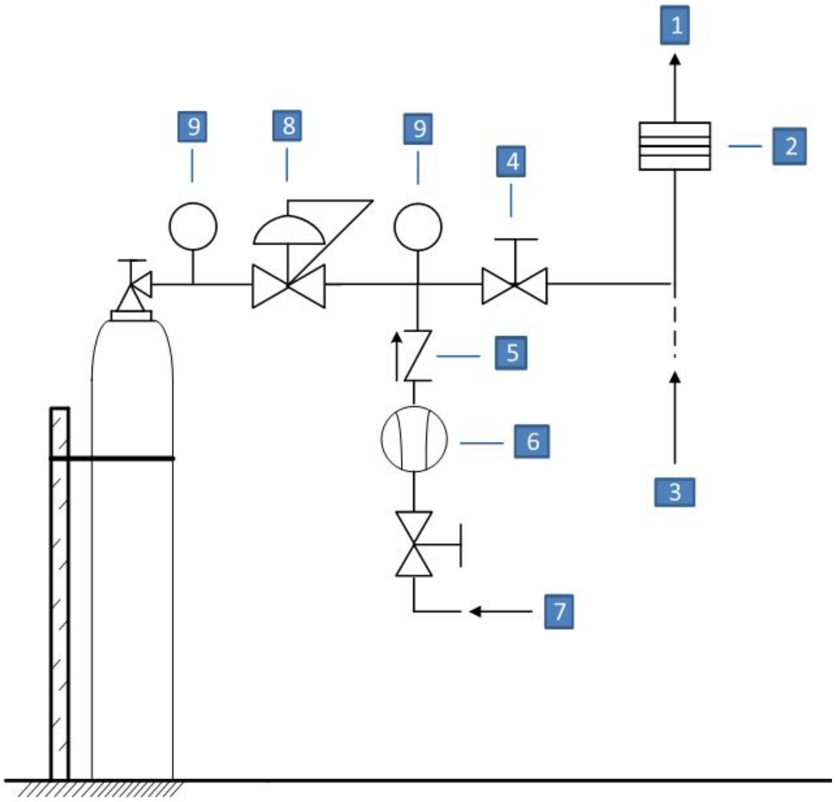
Checks shall be made to ensure that equipment is operating correctly, especially that air flow is maintained throughout the disposal operation.

Consideration should be given to prevailing meteorological conditions to ensure safe dispersion of vented gases.

If this method is used to dispose flammable gases, the flowrate of the dilution gas has to be calculated to ensure that the resulting concentration of the flammable gas in the exhaust flow is less than 50% of its lower explosive limit (LEL).

After concluding disposal operations, all equipment should be decontaminated and / or neutralised. Equipment shall be maintained as many gases can be damaging to equipment.

5.3.4.3 Method 4C—Controlled release through vent line



1. Discharge to a safe place
2. Flame arrestor
3. Diluent gas (if required)
4. Flow control valve
5. Non-return valve
6. Flow indicator
7. Inlet gas purge (if required)
8. Pressure control valve
9. Pressure indicator

NOTE—This is an illustrative example and not intended for design.

Figure 9—Method 4C: Controlled release through vent line

5.3.4.3.1 Description of method

Gas is discharged to atmosphere via a vent line terminating in a safe place (usually at high level) determined after a risk assessment. Dilution with inert gas is possible if required.

5.3.4.3.2 Application

This method can be used wherever there is a good reason to discharge the gas away from the gas source (for example, where the gas source is in a confined space.

5.3.4.3.3 Equipment

The vent line shall discharge to a safe place (usually at high level) away from persons and from incompatible processes and air intakes.

It is necessary to install a flow control system in the vent line (i.e., regulator and flow control valve). Where the system is to be used for the disposal of toxic or flammable gases, an inert gas purge should be installed. A suitable flame arrestor should also be incorporated when flammable gases are discharged. If a dilution gas is required, it should be fed into the vent line after the gas flow control system. The container shall be positively supported.

5.3.4.3.4 Operation

a) The container is connected to the vent line.

b) If the container content is flammable, air should be purged from the vent line by introduction of inert gas.

c) The vent line should be purged after discharge of toxic or flammable gases before disconnecting the cylinder.

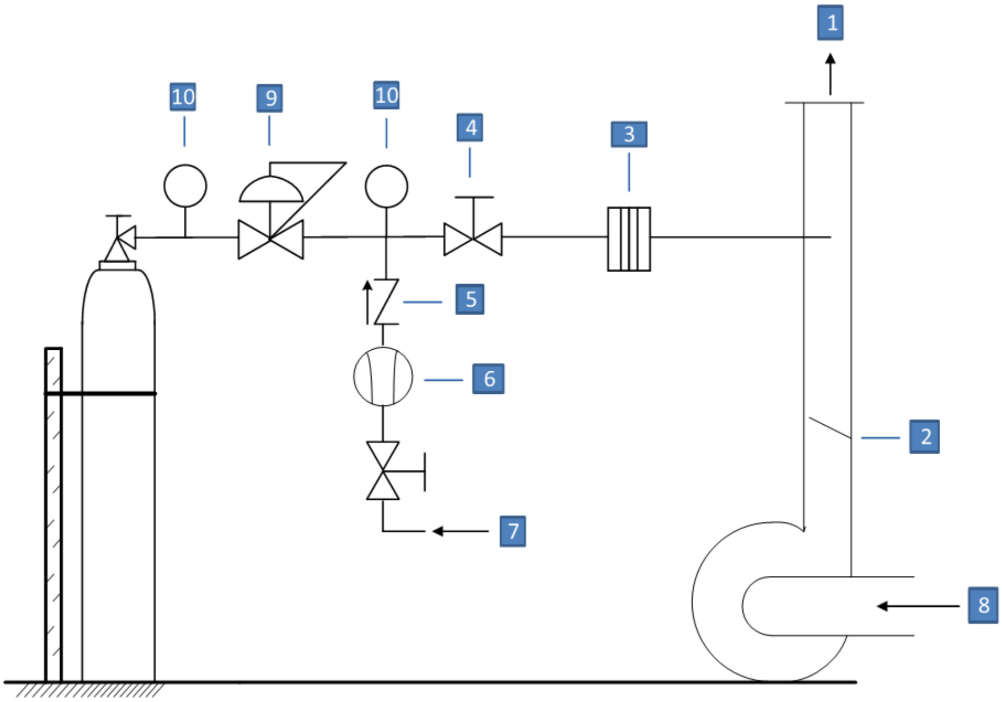
5.3.4.3.5 Operational precautions

Ignition sources (including open flames, electrical equipment, static discharge) should be excluded if the content of the container is flammable.

Consideration should be given to prevailing meteorological conditions to ensure safe dispersion of vented gases.

If this method is used to dispose flammable gases, the flowrate of the dilution gas has to be calculated to ensure that the resulting concentration of the flammable gas in the exhaust flow is less than 50% of its LEL.

5.3.4.4 Method 4D—Controlled dilution in forced air stream



1. Discharge to a safe place
2. Air flow indicator
3. Flame arrestor (if required)
4. Flow control valve
5. Non-return valve
6. Flow indicator
7. Inlet gas purge (if required)
8. Air intake
9. Pressure control valve
10. Pressure indicator

NOTE—This is an illustrative example and not intended for design.

Figure 10—Method 4D: Controlled dilution in forced air stream

5.3.4.4.1 Description of method

Gas is discharged at a controlled rate into a forced air stream. The diluted air / gas mixture is then discharged to a safe place (usually at high level).

5.3.4.4.2 Application

This method can be used for all gases, including toxic provided that the local regulations and operating permits are satisfied. The rate of discharge of some gases can be low due to the high levels of dilution required.

5.3.4.4.3 Equipment design

A pipe is connected from the container via a flow control system into a forced air stream designed to ensure adequate mixing of the gas with air. A venturi system can be used as an alternative to that shown in Figure 10. The dilute gas / air mixture is discharged to a safe place (usually at high level) away from persons, from incompatible processes, and air intakes. Where the system is to be used for the disposal of toxic or flammable gases, an inert gas purge should be installed. A suitable flame arrestor should also be incorporated when flammable gases are discharged.

To enable the level of dilution to be measured and controlled, flowmeters should be installed in both the gas pipeline and air stream.

5.3.4.4.4 Operation

a) The container is connected to the disposal system;

b) If the container content is flammable, air should be purged from the system with an inert gas such as nitrogen;

c) A positive check is made to ensure the air draft is functioning correctly;

d) The container discharge shall be controlled within a predetermined maximum flowrate;

e) The maximum container discharge rate is set to ensure that an acceptable dilution is reached before the point of discharge of the system to atmosphere;

f) Factors to be taken into account when establishing the maximum container discharge rate are:

  - nature of the gas or gas mixture
  - throughput of the forced air system
  - position of the discharge point and the local conditions and regulations; and

g) After discharge of toxic or flammable gases the system should be purged with inert gas such as nitrogen before disconnecting the container.

5.3.4.4.5 Operational precautions

Ignition sources (including open flames, electrical equipment, static discharge) should be excluded if the content of the container is flammable.

Care should also be taken to avoid build-up of potentially explosive flammable gas / air mixtures in and around the system.

Care should be taken to ensure that set discharge rates are not exceeded and that the forced air system is functioning correctly.

Consideration should be given to prevailing meteorological conditions to ensure safe dispersion of vented gases.

If this method is used to dispose flammable gases, the flowrate of the dilution gas has to be calculated to ensure that the resulting concentration of the flammable gas in the exhaust flow is less than 50% of its LEL.

6 Disposal of gas mixtures [1, 2, 3]

The disposal of compressed and liquefied gas mixtures shall meet the requirements of Sections 1, 2, and 5. The principal methods of disposal available are described in Section 5 and are the same used for pure gases.

The main characteristics of the gas mixtures dictate which methods of disposal are practical and effective. These include classification according to United Nations Globally Harmonised System of Classification and Labelling of Chemicals (UN GHS) and Regulation 1272/2008 *Classification, Labelling and Packaging of Substances and Mixtures* (CLP Regulation), material compatibility, and physical and chemical properties [8, 9]. The detailed characteristics of the gas mixture are available in the SDS.

It shall be noted that in some instances:

- hazards of some of the constituent gases can be reduced by the effect of dilution by other gases in the mixture; and

- hazards can be other than shown because of the presence of more than one reactive gas.

Therefore, it is essential to be aware firstly of the constituent gases and their proportions in the mixture, and secondly of the characteristics of the resultant mixture. With this information, a suitable disposal method can be chosen.

Further points for consideration are:

- Toxic components can be of a sufficiently low concentration to permit the use of a simpler method (such as Method 4) than that recommended for the individual component gases;

- Flammable components can be of a sufficiently low concentration as to render the mixture non-flammable and permit the use of a simpler method than that recommended for the individual component gases. Mixtures containing low concentration flammable gases can require incineration as simple burning might not work;

- Oxidants—The oxidant potential of the mixture shall be taken into account, especially where equipment is being used for a multiplicity of disposal applications. Oxidants should be purged from systems using an inert gas such as nitrogen before and after introduction of flammable gases;

- Pressure—The pressure of the mixture shall be established. Compared with the normal cylinder pressure of the component, which determines the disposal method, the mixture cylinder pressure can be substantially higher. Other types of pressure reducing devices could be necessary; and

- Container evacuation—This is frequently required after disposal of the container's contents to atmospheric pressure. Where evacuation is necessary, consideration shall be given to the treatment of the exhaust gas from the vacuum system. It can also be desirable to install an inert gas supply into the vacuum system to enable complete removal of all traces of the mixture from the container.

NOTE—Certain components can leave low vapour pressure contaminants in the container that cannot be evacuated.

CAUTION: *When emptied of their contents, diborane and diborane mixture cylinders often have a residual coating of higher boranes on the internal surface of the cylinder. These higher boranes are extremely unstable and can react violently with many chemicals including water and weak solutions of hydrogen peroxide. See 8.5.1.*

7 Identification of container contents [1, 2, 10]

7.1 Introduction

The gas industry as a whole is careful to ensure that the content is properly identified. Normally, operators deal with containers that they are familiar with and whose contents are well identified.

However, from time to time operators are faced with unfamiliar containers. These can come from another country, from another supplier, or have been stored for long periods under poor conditions. Extended storage can lead to loss of obvious container contents identification.

The purpose of this section is to guide the operator towards positive identification of the container content, even when obvious labelling, etc., has been lost. See Figure 11

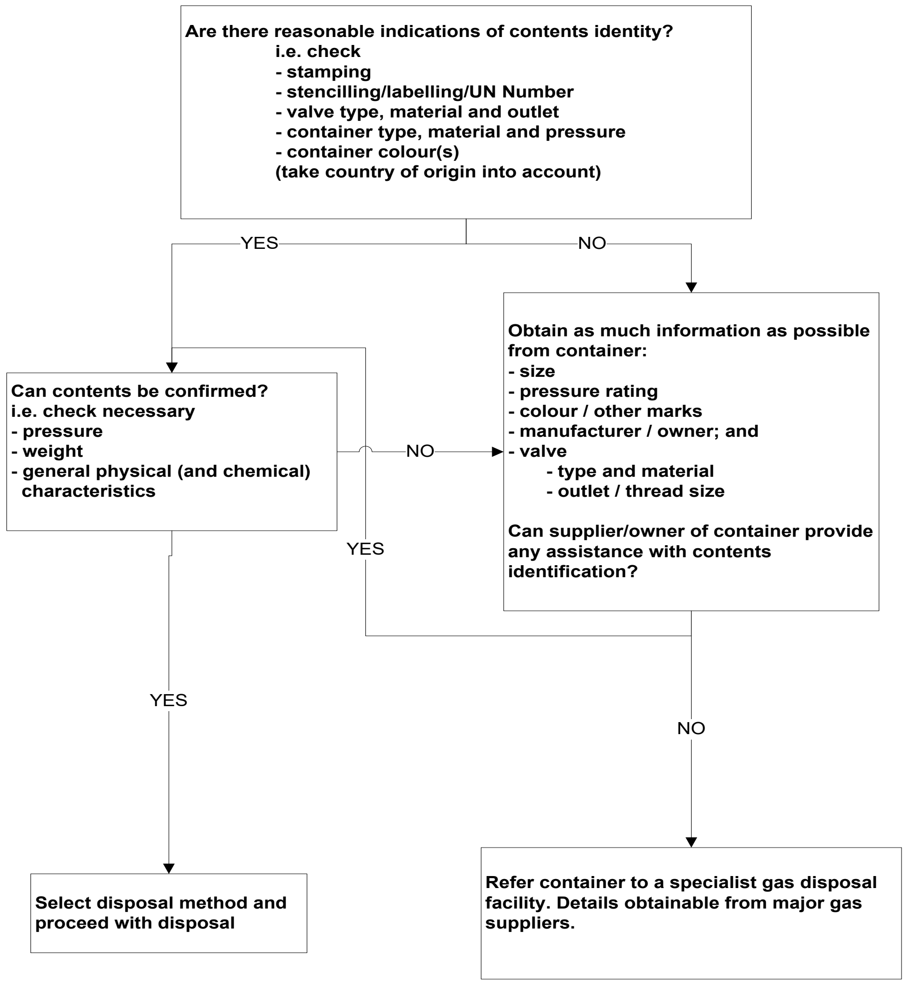


Figure 11—Flowchart for identification of container contents

7.2 Identification by product name

Care shall be taken that the conclusion as to the content of the cylinder is correct.

The name of the gas shall be the primary method of identification. Methods of identifying the content (in order of importance) include one or more of the following:

- gas name stenciled on the container;
- durable label attached to the container;
- label or tag attached to the cylinder valve; and
- permanent engraving or stamping of the container (usually on the shoulder or on a shoulder plate) with the gas name, chemical formula, or both.

The first step is to look for such an identification and check that it is compatible with all other information that is known about the container

Sometimes the product can be found to be marked with an unfamiliar synonym, or in a foreign language. If the chemical formula is missing, consult the European Chemicals Agency (ECHA) website, where chemical names are available for all registered chemical substances.

7.3 Indication by valve outlet connection, pressure relief device, and / or valve type

Many countries have legislation or codes of practice specifying valve outlet connections for various gases. Often, gases are grouped by chemical and physical properties for the purpose of valve outlet designation.

The relevant standards and codes of practice both from national authorities and from the supply companies should be available. Refer to:

- EIGA Doc 97, *Valve Outlet Connections for Gas Cylinders* [11];
- CGA S-1.1, *Pressure Relief Device Standards—Part 1—Cylinders for Compressed Gases* [12];
- CGA S-7, *Standard Method for Selecting Pressure Relief Devices for Compressed Gas Mixtures in Cylinders* [13];
- BS 341-1, *Transportable gas container valves. Specification for industrial valves for working pressures up to and including 300 bar* [14];
- EN 850, *Transportable gas cylinders. Pin-index, yoke-type valve outlet connections for medical use* [15];
- DIN 477-1, *Gas Cylinder Valves Rated for Cylinder Test Pressures up to 300 Bar—Part 1: Valve Inlet and Outlet Connections* [16];
- NF E29-650, *Gas cylinders. Valve outlet connections* [17];
- JIS B 8246, *Valves for high pressure gas cylinders* [18]; and
- JIS B 8244, *Valves for dissolved acetylene cylinder* [19].

The material and pressure rating of the valve can eliminate a whole range of gases, thus assisting with the identification.

When dealing with difficult instances of identification of containers, the condition of the valve outlet could be a guide to the gases contained. Observation and analysis of deposit at the valve outlet can assist.

Many countries have legislation or codes of practice mandating that PRDs are prohibited for use with highly toxic gases.

There are a number of valve types such as tied diaphragm, diaphragm, packed, etc., that may aid in identifying the contents of the container.

7.4 Indication by hazard labels

International transport agreements or regulations (International Maritime Dangerous Goods [IMDG] Code; International Civil Aviation Organization [ICAO]; Agreement on Dangerous Goods by Road [ADR]; Regulations Concerning International Transport of Dangerous Goods by Rail [RID], U.S. DOT, Transport Canada [TC]) require suppliers to affix hazard labels that indicate the hazard properties (flammability, corrosivity, toxicity, etc.) of the content. These give guidance to the type of gas contained and also eliminate a wide range of gases that will not come into the category covered by the hazard label.

7.5 Indication by type of container

Examination of the type of container can again reduce the range of possible contents.

As a general rule, low pressure welded containers usually contain low pressure liquefiable gases, and high pressure seamless containers usually contain high pressure permanent or liquefiable gases.

Material of construction of the container may also be a guide at least by eliminating gases incompatible with the material.

7.6 Indication by container markings

The container may be permanently marked with the name of the current owner, and contact with the owner could establish details of the contents

7.7 Identification by colour

Colours may be used in some geographies to identify products contained, but this shall be regarded as an aid to product identification, the primary identification being by the written name (see 7.2). Care shall be taken when using colour for establishing the content of a cylinder due to this potential issue.

In Europe, according to European standard EN 1089-3, *Transportable gas cylinders. Gas cylinder identification (excluding LPG). Colour coding*, particular colours will be used to indicate the hazard(s) of the content [20]. These identification markings will be in the form of coloured bands at the valve end of the container.

The shortcomings of the colour identification of contents are:

- There is a wide range of custom and practice throughout the world, so that the markings of a container moving across a border can give a totally erroneous indication of contents to the operator used to a different colour marking system; and

- While it is possible to cover most of the standard gases with a unique colour coding, there is a practical limit to the colours and colour combinations available so that it is impossible to have a unique colour coding for all gases and mixtures of gases. Cylinders sometimes have received many coats of paint during their lifetime. When cylinders have been left for an extended period of time, the final coat of paint could have deteriorated and been lost completely from the cylinder.

7.8 Confirmation of indications of contents

In the absence of positive identification, it has been seen previously that an indication of contents could be obtained from coloured bands, from hazard labels, from the type of container and type and condition of valve, and from information supplied by the container owner or manufacturer. It is still important, having obtained such guidance to the likely contents, to confirm those indicators by relating them to the pressure in the container, the weight of the contents (assuming the tare weight of the container can be established), and by carrying out a check on the general chemical and physical characteristics of the contents.

Once identification has been positively established, it is possible to go forward with choosing a disposal method and carrying it through.

In the event of failure to identify and confirm the contents of a container, the container shall be referred to a specialist disposal facility. Details of specialist facilities are obtainable from major compressed gas suppliers.

8 Disposal of non-serviceable containers [21, 22, 23, 24, 25, 26, 27]

This section covers the disposal of cylinders and containers once they have been emptied of product and purged.

8.1 Introduction

There are several industry publications on the subject of container disposal (see Section 9).

Each facility disposing of gas containers shall implement written de-valving and purging procedures based on industry standards. While covering the key points of safe container disposal, this section is primarily concerned with the provision of practical guidance on the problems that can arise when dealing with certain gases. Therefore, it is recommended that this section is used in conjunction with one of the industry publications on this subject.

Note that this section excludes the disposal of dissolved acetylene containers where special requirements beyond the scope of this section apply.

8.2 Ensuring the container is empty

Containers shall not be de-valved until a positive check has been made to ensure the container is empty. The following should be noted:

- All gases—A check should be made to ensure the container valve (and any attachment such as siphon tube) is clear of obstruction. This can be achieved by introducing a low pressure (for example, 0.2 bar [3 psi]) of a suitable gas such as nitrogen into the container and checking that it is subsequently discharged. In the case of toxic and flammable gases, this check may be incorporated into the purging procedures;

- Corrosive / reactive gases—Ensure the valve or dip pipe is not blocked by corrosion / reaction products. Check that no suck back of water or other reaction chemical has occurred by weighing the container (the container could appear empty by pressure check). Where it is suspected that such contamination is present, see 8.5;

- Liquefiable gases—Ensure the container has warmed up to ambient temperature. Discharge of the gas phase of a liquefiable gas can result in a lowering of the liquid phase temperature so the vapour pressure could decrease to atmospheric pressure. In cases of doubt, check that the container is empty by weighing and comparing it to the stamped tare weight of the cylinder; and

- Gases subject to polymerisation—Check that the container is empty by weight. Such gases (especially ethylene oxide) can form a polymer membrane inside the container under which liquid can remain.

8.3 Purging containers

Empty vessels that have contained toxic or flammable gases can still be potentially hazardous because of the residual gas or residue remaining at atmospheric or slightly elevated pressure.

The residue (at atmospheric or slightly elevated pressure) should be removed by inert gas such as nitrogen purging and / or evacuation of the container. The extent of purging and evacuation required depends on the properties of the gas. For example, a flammable gas or low toxicity gas container could only require minimal purging to render it safe, whereas a highly toxic gas container can require repeated purging / evacuation cycles before being considered safe to de-valve.

8.4 De-valving

Before de-valving a container, the operator shall ensure that:

- it is depressurised by carrying out the check described in 8.2 immediately prior to de-valving;

- any residual toxic or flammable gases are at a safe concentration as a result of purging;

- there shall be adequate controls on the operation such as a system of certification that purging has been carried out where appropriate; and

- due account has been taken of the possibility of non-gaseous residues that could be potentially hazardous (see 8.5).

8.5 Potentially hazardous residues

Containers that have contained certain toxic, corrosive, or liquefiable gases can also contain potentially hazardous solid or liquid residues, even after the container has been emptied, purged, and de-valved. Some residues can be found by visual inspection while others shall be assumed to exist because of the nature of the contained gas. Such residues shall be removed before the container is destroyed and sent for scrap. Some examples of typical residues that can be encountered and notes on their removal are given as follows:

- Oily residues—All containers should be checked for excessive oily residues. These can usually be removed by washing with a suitable solvent followed by purging. Some solvent washings and residues might need to be disposed of as hazardous waste in accordance with local legislation;

- Salts and corrosive residues—These can be encountered when dealing with containers that have contained acid or alkaline gases. Such residues can usually be removed by washing with water (hot water in some cases);

- Polymers—These can be found in containers that have polymerisable products such as ethylene oxide, butadiene, etc. Such polymers can usually be broken down by prolonged soaking with water or by the use of solvents. Polymers of diborane can only be removed by the use of solvents (see 8.5.1);

- Toxic metal oxides—Containers that have contained metal hydrides such as arsine, hydrogen selenide, hydrogen telluride, stibine, germane, etc. shall be assumed to contain toxic oxides or other decomposition products. These can usually be satisfactorily removed with an oxidising acid solution.

- Cyanide residues—These shall be assumed for containers that have contained cyanides and can be removed with a suitable alkaline solution.

CAUTION*—The decontamination of cylinders that have contained cyanides shall only be undertaken by trained industry experts following a detailed risk assessment. Consideration shall be given to:*

- *Residual pressure in the cylinder and possible reaction of hydrogen cyanide with the steel cylinder to liberate hydrogen;*

- *Highly toxic nature of any cyanide residues;*

- *PPE and apparatus required to safely remove and treat the cyanide residues; and*

- *Availability of cyanide antidotes and first aid / medical support during disposal activities.*

Care shall be taken to ensure the safe disposal of all chemicals, etc. used for the removal of potentially hazardous residues from containers (particularly concerning cyanides).

8.5.1 Hazards associated with diborane, diborane mixtures, and pentaborane

This section addresses the risks involved in the handling of diborane, diborane mixture, and pentaborane cylinders. Extreme caution shall be observed. Only specially trained and qualified personnel should attempt to clean or decontaminate a diborane or pentaborane cylinder.

NOTE—Although it is not commercially available, pentaborane is a decomposition product of diborane and can be present in residuals or empty cylinders.

Do not open the valve on a diborane or pentaborane cylinder that is not connected to an engineered system for disposal, cleaning, and purging of such cylinders and that has not been properly cleaned and decontaminated. Dispose or hydrotest a diborane or pentaborane cylinder only after verifying that it has been properly cleaned and decontaminated. It is important to realise that partially full and empty cylinders in diborane or pentaborane service contain hazardous product residue. Diborane, pentaborane, and their decomposition product residues can react with air and water, creating products that can overpressure a cylinder. Serious injury to personnel and property can result. Cylinders can burst emitting highly toxic substances that can cause fatalities.

8.5.1.1 Chemistry and hazardous nature of products

Diborane is a compressed gas that is highly toxic and unstable. The Occupational Safety and Health Administration (OSHA) lists the Permissible Exposure Limit (PEL) for an 8-hour Time-Weighted Average (TWA) of 0.1 ppm (0.11 mg/m³) for diborane [28].

Diborane decomposes slowly into higher boranes and hydrogen at ambient temperature during storage. The amount and rate of decomposition is dependent upon temperature, pressure, and other factors. The decomposition is described as follows:

$$B_2H_{6\,(g)} \rightarrow B_5H_{9\,(l)} + B_{10}H_{14\,(s)} + B_xH_{y\,(l/s)} + H_{2\,(g)} \text{ (not balanced)}$$

Although many higher boranes are formed, the most hazardous decomposition products of diborane are pentaborane, decaborane, and boron hydride polymers.

Pentaborane is a volatile, pyrophoric, highly toxic, and colourless liquid. OSHA lists a PEL–TWA of 0.005 ppm (0.01 mg/m³) for pentaborane [28]. Pentaborane can also decompose into higher boranes.

Decaborane is often recognised by white, needle-like crystals that can appear pale yellow in an impure state. OSHA lists a PEL–TWA of 0.05 ppm (0.3 mg/m³) [28]. For more information, see the gas supplier's safety data sheet (SDS) [29].

In addition to the inhalation hazards, decaborane is an extremely toxic dermal irritant affecting the central nervous system. The Registry of Toxic Effects of Chemical Substances (RTECS) LD_{50} skin for rabbit is 71 mg/kg [30].

Decaborane can be explosive on contact with flame or heat or with oxygenated or halogenated solvents. Many of these decaborane solutions can decompose very rapidly resulting in a release of heat and hydrogen, often with disastrous results.

All of these higher boranes have the potential to be very reactive and very toxic. Some even form shock-sensitive compounds. Some of these higher boranes react very exothermically with water or base-evolving hydrogen. This combination can create an explosive condition. Others react very slowly with water at ambient temperatures posing a greater risk from their toxicity. Only qualified personnel should handle these chemicals and associated equipment.

8.5.1.2 Specific precautions and actions

If diborane or pentaborane has been emptied from a cylinder by purging and / or evacuation, the hazards due to decomposition product residue still remain. Cylinders that have been emptied shall clearly state that the cylinder was in diborane or pentaborane service. Cylinders shall be properly cleaned and decontaminated before processes that require removing the valve from the cylinder including disposal or requalification by hydrotest. Some key points to remember are:

- An emptied cylinder could develop considerable pressure over time, due to decomposition of the solid residue. The pressure is due to hydrogen gas, and should be vented properly before attempting to de-valve the cylinder;

- A refilled cylinder can develop solid residue accumulation. This accumulation should be monitored and appropriate action taken when accumulation is excessive;

- Purge and evacuate just before de-valving; and

- During the cleaning process, never plug or valve a cylinder while water or other solution remains inside.

Never attempt to wash a cylinder with the valve installed unless the consequences of the reaction process are fully understood and provisions are made for the control of pressure so the cylinder does not rupture. The method and the equipment used shall be planned, analysed, tested, and validated to ensure that the process is conducted safely and in an environmentally sound manner. Only specially trained and qualified personnel who are fully aware of all the hazards, proper methods, and equipment should attempt to clean, dispose, or decontaminate a diborane or pentaborane cylinder.

Besides diborane and pentaborane, many other gases are extremely dangerous to handle. One should not attempt to decontaminate, requalify, or remediate gas cylinders without in-depth knowledge of the chemistry, physical properties, toxicity, and hazards of the gas or gases in question and of cylinder and equipment limitations. Refer to CGA P-22, *The Responsible Management and Disposition of Compressed Gases and their Cylinders* for more information [31].

8.6 Rendering containers unserviceable

Where containers are considered unsuitable for further service, they should be rendered unserviceable before sending them to scrap merchants, etc. This is to prevent subsequent illegal use, which could be extremely hazardous and can result in an incident. Rendering unserviceable can include one or more of the following according to legislation / regulation and / or written procedures:

- cutting the container into pieces;
- burning a hole in the container (preferably on the shoulder); and / or
- destroying the valve threads.

9 References

Unless otherwise specified, the latest edition shall apply.

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[4] EIGA TB 21, *Recommendations for Cooling and Heating of Gas Cylinders*, www.eiga.eu.

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[6] Directive 2014/31/EU, *Equipment for potentially explosive atmospheres* (ATEX), www.europa.eu.

[7] NFPA 497, *Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*, www.nfpa.org.

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[9] Regulation (EC) 1272/2008, *Classification, Labelling and Packaging of Substances and Mixtures*, www.europa.eu.

[10] EIGA Doc 169, *Classification and Labelling guide in accordance with EC Regulation 1272/2008*, www.eiga.eu.

[11] EIGA Doc 97, *Valve Outlet Connections for Gas Cylinders*, www.eiga.eu.

[12] CGA S-1.1, *Pressure Relief Device Standards—Part 1—Cylinders for Compressed Gases*, www.cganet.com.

[13] CGA S-7, *Standard Method for Selecting Pressure Relief Devices for Compressed Gas Mixtures in Cylinders*, www.cganet.com.

[14] BS 341-1, *Transportable gas container valves. Specification for industrial valves for working pressures up to and including 300 bar*, www.bsi-global.com.

[15] EN 850, *Transportable gas cylinders. Pin-index, yoke-type valve outlet connections for medical use*, www.cen.eu.

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[19] JIS B 8244, *Valves for dissolved acetylene cylinder*, www.jsa.or.jp.

[20] EN 1089-3, *Transportable gas cylinders. Gas cylinder identification (excluding LPG). Colour coding*, www.cen.eu.

[21] ISO 18119, *Gas cylinders — Seamless steel and seamless aluminium-alloy gas cylinders and tubes — Periodic inspection and testing*, www.iso.org.

[22] ISO 10460, *Gas cylinders — Welded aluminium-alloy, carbon and stainless steel gas cylinders — Periodic inspection and testing*, www.iso.org.

[23] ISO 10461, *Gas cylinders — Seamless aluminium-alloy gas cylinders — Periodic inspection and testing*, www.iso.org.

[24] EIGA Doc 129, Pressure Receptacles with Blocked or Inoperable Valves, www.eiga.eu.

[25] CGA-P-38, *Guideline for Devalving Cylinders*, www.cganet.com.

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[27] EIGA Info 18, *Devalving Gas Cylinders*, www.eiga.eu.

[28] *Code of Federal Regulations*, Title 29 (Labor), Parts 1900-1910, www.gpo.gov.

[29] Gas supplier's safety data sheet.

[30] *Registry of Toxic Effects of Chemical Substances (RTECS®)*, www.mdl.com.

[31] CGA P-22, *The Responsible Management and Disposition of Compressed Gases and their Cylinders*, www.cganet.com.

Appendix A—Gas characteristics and recommended disposal methods

At a minimum, ensure that a copy of the SDS is available to personnel and personnel are trained in the use of the SDS and other applicable reference materials.

EIGA SDS	Usual Name	Chemical formula	CAS Registry Number	Disposal method	Key characteristics and operational and safety considerations
001	Acetylene (dissolved)	C_2H_2	74-86-2	1: Recycling 3A: Direct combustion 3C: Incineration 4C: Controlled release through vent line	Subject to exothermic self-decomposition, if not stabilised Gas in cylinder is dissolved in solvent/porous mass Avoid copper, silver, and mercury Use steel, wrought iron, or brass containing less than 70% copper Flashback arrestors shall be used $C_2H_2 + 2{,}5\ O_2 \rightarrow 2\ CO_2 + H_2O$ (Methods 3A and 3C) Limit pressure to less than 1 bar.
002	Ammonia	NH_3	7664-41-7	1: Recycling 2A: Discharge to simple scrubber 2B: Discharge into counterflow scrubber	Avoid copper, tin, zinc, mercury and Viton Beware suck back of water $NH3 + H+ \rightarrow NH4+$ (Methods 2A and 2B)
003A	Argon	Ar	7440-37-1	1: Recycling 4A: Direct discharge from container valve 4B: Direct discharge from container valve into fume cubicle or hood 4C: Controlled release through vent line	
004	Arsenic pentafluoride	AsF_5	7784-36-3	1: Recycling 2B: Discharge into counterflow scrubber	Use nickel, Monel®, heavy gauge mild steel Use hard rubber, polyvinyl chloride (PVC) for moist gas $AsF_5 + 8\ OH^- \rightarrow AsO_4^{3-} + 5\ F^- + 4\ H_2O$
Not listed	Arsenic trifluoride	AsF_3	7784-35-2	1: Recycling 2B: Discharge into counterflow scrubber	Use nickel, Monel, heavy gauge mild steel Use hard rubber, PVC for moist gas $AsF_3 + 6\ OH^- \rightarrow AsO_3^{3-} + 3\ F^- + 3\ H_2O$
005	Arsine	AsH_3	7784-42-1	1: Recycling 2B: Discharge into counterflow scrubber 2C: Direct discharge to solid-state adsorber 3C: Incineration gas phase + filtration 4B+2C: Dilution and discharge to solid-state adsorber	Fast acting, irreversible, systemic poison Elemental arsenic can be present in cylinder and lines $AsH_3 + 4\ H_2O \rightarrow AsO_4^{3-} + 11\ H^+ + 8e^-$ (Method 2B) Oxidants that can be used include permanganate or hypochlorite Adsorption on charcoal or on $CuSO_4$ treated silica gel $3\ CuSO_4 + 2\ AsH_3 \rightarrow Cu_3As_2 + 3\ H_2SO_4$ (Method 2C)
Not listed	Boron tribromide	BBr_3	10294-33-4	1: Recycling 2B: Discharge into counterflow scrubber	$BBr_3 + 3\ OH^- \rightarrow BO_3^{3-} + 3\ HBr$ (Methods 2B)

EIGA SDS	Usual Name	Chemical formula	CAS Registry Number	Disposal method	Key characteristics and operational and safety considerations
006	Boron trichloride	BCl_3	10294-34-5	1: Recycling 2A: Direct discharge into simple scrubber 2B: Discharge into counterflow scrubber	Use copper, Monel, Hastelloy, heavy gauge mild steel, PVC or polytetrafluoroethylene (PTFE) Ensure that blockage by corrosion products does not give false indication of empty cylinder or system $4\ BCl_3 + 14\ NaOH \rightarrow 12\ NaCl + Na_2B_4O_7 + 7\ H_2O$ (Methods 2A and 2B)
007	Boron trifluoride	BF_3	7637-07-2	1: Recycling 2B: Discharge into counterflow scrubber	Avoid PVC Use copper, heavy gauge mild steel, (aluminium), PTFE, polyethylene Beware of danger of hydrofluoric acid formed (risk of severe chemical burns) Ensure that blockage by corrosion products does not give false indication of empty cylinder or system Unwanted residual gases shall be securely contained and safely transported to a facility properly equipped and staffed for disposal $16\ BF_3 + 14\ NaOH \rightarrow 12\ NaBF_4 + Na_2B_4O_7 + 7\ H_2O$ (Method 2B)
Not listed	Bromine trifluoride	BrF_3	7787-71-5	1: Recycling 4B+2B: Dilution and discharge into counterflow scrubber	Unwanted residual gases shall be securely contained and safely transported to a facility properly equipped and staffed for disposal Avoid grease and all other combustible contaminants Use Monel nickel or heavy gauge mild steel and PTFE Preclean and passivate all materials in use Reacts violently with water Initially introduce only small quantities until one is convinced system is passivated
008	Bromochlorodifluoromethane (R12B1)	$CBrClF_2$	353-59-3	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber, etc., with liquid
009	Bromomethane	CH_3Br	74-83-9	1: Recycling 3C+2B: High temperature Incineration followed by discharge into counterflow scrubber	Systemic poison with persistent and sometimes delayed effects Avoid aluminium, magnesium and zinc Avoid plastics, rubber etc., with liquid. Use other common metals and PTFE. Toxic products produced by burning. $CH_3Br + 1{,}5\ O_2 \rightarrow CO_2 + H_2O + HBr$ (Method 3C) $HBr + OH^- \rightarrow H_2O + Br^-$ (Method 2B)

EIGA SDS	Usual Name	Chemical formula	CAS Registry Number	Disposal method	Key characteristics and operational and safety considerations
010	Bromotrifluoroethylene (R113B1)	C_2BrF_3	598-73-2	1: Recycling 3C+2B: High temperature Incineration followed by discharge into counterflow scrubber	Avoid alloys with greater than 2% magnesium, aluminium, and plastics. Use other common metals and PTFE.
011	Bromotrifluoromethane (R13B1)	CF_3Br	75-63-8	1: Recycling 3C+2B: High temperature Incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid.
012	1,2-Butadiene	C_4H_6	590-19-2	1: Recycling 3A: Direct combustion 3B: Combustion/incineration	Avoid plastics, rubber etc., with liquid. $C_4H_6 + 5{,}5\ O_2 \rightarrow 4\ CO_2 + 3H_2O$ (Methods 3A and 3B)
013	1,3-Butadiene	C_4H_6	106-99-0	1: Recycling 3A: Direct combustion 3B: Combustion/incineration	Subject to self-polymerisation Avoid plastics, rubber etc., with liquid. Guard against polymer blockage. Check that content is stable: i.e., no temperature rise of cylinder. $C_4H_6 + 5{,}5\ O_2 \rightarrow 4CO_2 + 3H_2O$ (Methods 3A and 3B)
075	iso-Butane (R600a)	C_4H_{10}	75-28-5	1: Recycling 3A: Direct combustion 3B: Combustion/incineration	Avoid plastics, rubber etc. with liquid. $C_4H_{10} + 6{,}5\ O_2 \rightarrow 4CO_2 + 5H_2O$ (Methods 3A and 3B)
014	n-Butane	C_4H_{10}	106-97-8	1: Recycling 3A: Direct combustion 3B: Combustion/incineration	Avoid plastics, rubber. $C_4H_{10} + 6{,}5\ O_2 \rightarrow 4CO_2 + 5H_2O$ (Methods 3A and 3B)
017	1-Butene	C_4H_8	106-98-9	1: Recycling 3A: Direct combustion 3B: Combustion/incineration	Avoid plastics, rubber, etc., with liquid. $C_4H_8 + 6\ O_2 \rightarrow 4\ CO_2 + 4\ H_2O$ (Methods 3A and 3B)
015	cis-2-Butene	C_4H_8	590-18-1	1: Recycling 3A: Direct combustion 3B: Combustion/incineration	Avoid plastic, rubber etc., with liquid. $C_4H_8 + 6\ O_2 \rightarrow 4\ CO_2 + 4\ H_2O$ (Methods 3A and 3B)
076	Iso-Butene	C_4H_8	115-11-7	1: Recycling 3A: Direct combustion 3B: Combustion/incineration	Avoid plastics, rubber, etc., with liquid. C4H8 + 6 O2 $\rightarrow$ 4 CO2 + 4 H2O (Methods 3A and 3B)
016	trans-2-Butene	C_4H_8	624-64-6	1: Recycling 3A: Direct combustion 3B: Combustion/incineration	Avoid plastics, rubber, etc., with liquid. C4H8 + 6 O2 $\rightarrow$ 4 CO2 + 4 H2O (Methods 3A and 3B)

EIGA SDS	Usual Name	Chemical formula	CAS Registry Number	Disposal method	Key characteristics and operational and safety considerations
018A	Carbon dioxide	CO_2	124-38-9	1: Recycling 4A: Direct discharge from container valve 4B: Direct discharge from container valve into fume cubicle or hood 4C: Controlled release through vent line unless restricted by local regulation	Cryogenic solid can cause cold burns Guard against dry ice blockage
019	Carbon monoxide	CO	630-08-0	1: Recycling 3A: Direct combustion 3C: Incineration	Beware of possibility of toxic carbonyls remaining in the cylinder after emptying. $CO + 0,5\ O_2 \rightarrow CO_2$ (Methods 3A and 3C)
020	Carbonyl fluoride	COF_2	353-50-4	1: Recycling 2B: Discharge into counterflow scrubber 2C: Discharge into solid-state adsorber 4B+2C: Dilution and discharge to solid-state adsorber	Beware of formation of hydrofluoric acid Risk for severe chemical burns Avoid plastics, rubber, etc., with liquid Use copper, Monel, nickel, heavy gauge mild steel and PTFE $COF_2 + 4\ OH^- \rightarrow CO_3^{2-} + 2\ F^- + 2\ H_2O$ (Method 2B) Adsorption on soda lime (Method 2C)
021	Carbonyl sulphide	COS	463-58-1	1: Recycling 3C+2A/B: Incineration followed by discharge to scrubber 2C: Discharge into solid-state adsorber 4B+2C: Dilution and discharge to solid-state adsorber	Avoid plastics, rubber, etc., with liquid Use aluminium, stainless steel, PTFE $COS + 1,5\ O_2 \rightarrow CO_2 + SO_2$ (Method 3C) $SO_2 + 2\ OH^- \rightarrow SO_3 + H_2O$ (Methods 2A and 2B) Adsorption on soda lime (Method 2C)
022	Chlorine	Cl_2	7782-50-5	1: Recycling 2A: Discharge into simple scrubber 2B: Discharge into counterflow scrubber 4B+2C: Dilution and discharge to solid-state adsorber	Avoid grease and other combustible contaminants. Use heavy gauge mild steel, precleaned and passivated. $Cl_2 + 2\ OH^- \rightarrow Cl^- + ClO^- + H_2O$ $S_2O_3^{2-} + 4\ ClO^- + 2\ OH^- \rightarrow 2\ SO_4^{2-} + 4\ Cl^- + H_2O$ (Method 2B) Adsorption on soda lime (Method 2C)

EIGA SDS	Usual Name	Chemical formula	CAS Registry Number	Disposal method	Key characteristics and operational and safety considerations
023	Chlorine pentafluoride	ClF_5	13637-63-3	1: Recycling 4B+2B: Dilution with inert gas and discharge into counterflow scrubber	The product shall not be disposed in its liquid phase due to its high reactivity The gas phase should be diluted because of its exothermic reaction Unwanted residual gases shall be securely contained and safely transported to a facility properly equipped and staffed for disposal Avoid grease and all other combustible contaminants Use copper, Monel, heavy gauge mild steel precleaned and passivated, and PTFE) Reacts violently with water Introduce initially only small quantities until the system is passivated $4ClF_5 + 24OH^- = 3ClO_4^- + Cl^- + 20F^- + 12H_2O$
024	Chlorine trifluoride	ClF_3	7790-91-2	1: Recycling 4B+2B: Dilution with inert gas and discharge into counterflow scrubber	The product shall not be disposed in its liquid phase due to its high reactivity The gas phase should be diluted because of its exothermic reaction Unwanted residual gases shall be securely contained and safely transported to a facility properly equipped and staffed for disposal Avoid grease and all other combustible contaminants Use copper, Monel, heavy gauge mild steel precleaned and passivated, and PTFE Reacts violently with water Introduce initially only small quantities until the system is passivated $3ClF_3 + 12OH^- = 2ClO_3^- + Cl^- + 9F^- + 6H_2O$
025	Chlorodifluoroethane (R142b)	$C_2H_3ClF_2$	75-68-3	1: Recycling 3C+2B: High temperature Incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid
026	Chlorodifluoroethylene (R1122)	C_2HClF_2	359-10-4	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Avoid plastic, rubber, etc., with liquid
027	Chlorodifluoromethane (R22)	$CHClF_2$	75-45-6	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid

EIGA SDS	Usual Name	Chemical formula	CAS Registry Number	Disposal method	Key characteristics and operational and safety considerations
028	Chloroethane	C_2H_5Cl	75-00-3	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Avoid aluminium, magnesium, and zinc Avoid plastics, rubber etc., with liquid $C_2H_5Cl + 3\ O_2 \rightarrow 2\ CO_2 + HCl + 2\ H_2O$ (Method 3C) $HCl + OH^- \rightarrow Cl^- + H_2O$ (Method 2B)
029	Chloromethane	CH_3Cl	74-87-3	1: Recycling 3C+2B: Incineration followed by discharge into counterflow scrubber	Avoid aluminium Avoid plastics, rubber, etc., with liquid Use other common materials, PTFE $CH_3Cl + 1{,}5\ O_2 \rightarrow CO_2 + HCl + H_2O$ (Method 3C) $HCl + OH^- \rightarrow Cl^- + H_2O$ (Method 2B)
Not listed	Chlorosilane	SiH_3Cl	13465-78-6	1: Recycling 2B: Discharge into counterflow scrubber 3C+2B: Incineration followed by discharge into counterflow scrubber	Avoid flowing liquid through nonelectrically conductive lines Ensure that blockage by corrosion/combustion products does not give false indication of empty cylinder or system Use Monel, heavy gauge mild steel if moist Forms hydrochloric acid in presence of water Avoid suck back of aqueous solutions $SiH_3Cl + 2\ NaOH + H_2O \rightarrow Na_2SiO_3 + HCl + 3\ H_2$ (Method 2B) $HCl + NaOH \rightarrow NaCl + H_2O$ (Method 2B) $SiH_3Cl + 1{,}5\ O_2 \rightarrow SiO_2 + HCl + H_2O$ (Method 3C)
031	Chlorotetrafluoroethane (R124a)	C_2HF_4Cl	2837-89-0	1: Recycling 3C+2B: High temperature Incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid
032	Chlorotrifluoroethane (R133a)	$C_2H_2F_3Cl$	75-88-7	1: Recycling 3C+2B: High temperature Incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid
033	Chlorotrifluoroethylene (R1113)	C_2ClF_3	79-38-9	1: Recycling 3C+2B: High temperature Incineration followed by into counterflow scrubber	Avoid plastics, rubber etc., with liquid
034	Chlorotrifluoromethane (R13)	$CClF_3$	75-72-9	1: Recycling 3C+2B: High temperature Incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid
035	Cyanogen	C_2N_2	460-19-5	1: Recycling 3C+2B: Incineration followed by discharge into counterflow scrubber	Fast acting irreversible systemic poison Use stainless steel, Monel, heavy gauge mild steel, and PTFE $C_2N_2 + 2\ O_2 \rightarrow 2\ CO_2 + N_2$ (Method 3C) Burning with hot, efficient flame Control combustion conditions to minimise formation of nitrogen oxides

EIGA SDS	Usual Name	Chemical formula	CAS Registry Number	Disposal method	Key characteristics and operational and safety considerations
036	Cyanogen chloride	$CNCl$	506-77-4	1: Recycling 2B: Discharge into counterflow scrubber	Fast acting irreversible systemic poison Use stainless steel, Monel, heavy gauge mild steel, and PTFE. $CNCl + 2 OH^- \rightarrow OCN^- + Cl^- + H_2O$ (pH > 11) $2 OCN^- + 3 OCl^- + 2 OH^- \rightarrow N_2 + 2 CO_3^{2-} + H_2O$ (Method 2B)
037	Cyclobutane	C_4H_8	287-23-0	1: Recycling 3A: Direct combustion 3B: Combustion/incineration	Avoid plastics, rubber, etc., with liquid $C_4H_8 + 6O_2 = 4CO_2 + 4H_2O$ (Methods 3A and 3B)
038	Cyclopropane	C_3H_6	75-19-4	1: Recycling 3A: Direct combustion 3B: Combustion/incineration	Avoid plastics, rubber, etc., with liquid. $C_3H_6 + 4{,}5\ O_2 \rightarrow 3\ CO_2 + 3\ H_2O$ (Methods 3A and 3B)
039	Deuterium	D_2	7782-39-0	1: Recycling 3A: Direct combustion 3C: Incineration 4C: Controlled release through vent line	$D_2 + 0{,}5\ O_2 \rightarrow D_2O$ (Methods 3A and 3C)
040	Diborane	B_2H_6	19287-45-7	2B: Discharge into counterflow scrubber 3B+2C: Incineration followed by discharge into counterflow scrubber	Beware possibility of higher boranes (spontaneously flammable) remaining in cylinder. Guard against polymer blockage $2\ B_2H_6 + 2\ OH^- + 5\ H_2O \rightarrow B_4O_7^{2-} + 12\ H_2$ (Method 2B) $B_2H_6 + 3\ O_2 \rightarrow B_2O_3 + 3\ H_2O$ (Method 3C) $B_2O_3 + 3\ H_2O \rightarrow 2\ H_3BO_3$ (Method 2B) Voluminous cloud of B_2O_3 can be produced Beware for blockage of pipework/nozzles by B_2O_3 See also 8.5.1
Not listed	Dibromodifluoromethane (R12B2)	CBr_2F_2	75-61-6	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid.
041	Dichlorodifluoromethane (R12)	CCl_2F_2	75-71-8	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid.
042	Dichlorofluoromethane (R21)	$CHCl_2F$	75-43-4	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid.

EIGA SDS	Usual Name	Chemical formula	CAS Registry Number	Disposal method	Key characteristics and operational and safety considerations
043	Dichlorosilane	SiH_2Cl_2	4109-96-0	1: Recycling 2B: Discharge into counterflow scrubber 3C+2B: Incineration followed by discharge into counterflow scrubber	Spontaneous ignition/self-decomposition is possible around 100°C (212 °F) or by shock Ensure that blockage by corrosion/combustion products does not give false indication of empty cylinder or system Use nickel, nickel steels, stainless steels, heavy gauge mild steel, and PTFE. Avoid flowing liquid through nonelectrically conductive lines. Forms hydrochloric acid and hydrogen in presence of water. $SiH_2Cl_2 + 2\ NaOH + H_2O \rightarrow Na_2SiO_3 + 2\ HCl + 2\ H_2$ (Methods 2B) $SiH_2Cl_2 + O_2 \rightarrow SiO_2 + 2\ HCl$ (Method 3C) $HCl + NaOH \rightarrow NaCl + H_2O$ (Method 2B)
Not listed	Dichloromethane (R30)	CH_2Cl_2	75-09-2	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid
045	Difluoroethane (R152a)	$C_2H_4F_2$	75-37-6	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid
046	1,1-Difluoroethylene (R1132a)	$C_2H_2F_2$	75-38-7	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Avoid plastic, rubber, etc., with liquid
130	Difluoromethane (R32)	CH_2F_2	75-10-5	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid
Not listed	Digermane	Ge_2H_6	13818-89-8	1: Recycling 2C: Discharge into solid-state adsorber 3C: Incineration gas phase + filtration	Ensure blockage by combustion products does not give false indication of empty cylinder or system High temperature decomposition products are toxic $Ge_2H_6 + 3{,}5\ O_2 \rightarrow 2\ GeO_2 + 3\ H_2O$ (Method 3C)
048	Dimethyl ether	C_2H_6O	115-10-6	1: Recycling 3A: Direct combustion 3B: Combustion/incineration	Avoid plastics, rubber etc., with liquid. $C_2H_6O + 3\ O_2 \rightarrow 2\ CO_2 + 3\ H_2O$ (Methods 3A and 3B)

EIGA SDS	Usual Name	Chemical formula	CAS Registry Number	Disposal method	Key characteristics and operational and safety considerations
047	Dimethylamine	C_2H_7N	124-40-3	1: Recycling 2A: Direct discharge into simple scrubber 2B: Discharge into counterflow scrubber 2C: Discharge into solid-state adsorber 3C+2A/B: Incineration followed by discharge to scrubber	Avoid copper, nickel, mercury, tin, zinc Avoid plastics, rubber, etc., with liquid Use steel and PTFE $2\ C_2H_7N + 7{,}5\ O_2 \rightarrow 4\ CO_2 + 7\ H_2O + N_2$ Control combustion conditions to minimise nitrogen dioxide production (Method 3C) $2\ (CH3)_2NH + H_2SO_4 \rightarrow 2\ (CH3)_2NH_2^+ + SO_4^{2-}$ (Methods 2A and 2B) Adsorption on activated charcoal (Method 2C)
087	2,2-Dimethyl-propane (Neopentane)	C_5H_{12}	463-82-1	1: Recycling 3A: Direct combustion 3B: Combustion/incineration	Avoid plastics, rubber etc., with liquid $C_5H_{12} + 8\ O_2 \rightarrow 5\ CO_2 + 6\ H_2O$ (Methods 3A and 3B)
049	Dimethylsilane	$(CH_3)_2SiH_2$	1111-74-6	1: Recycling 3C: Incineration gas phase + filtration	Ensure blockage by combustion products does not give false indication of empty cylinder or system $(CH_3)_2SiH_2 + 5\ O_2 \rightarrow 2\ CO_2 + SiO_2 + 4\ H_2O$ (Method 3C)
050	Disilane	Si_2H_6	1590-87-0	1: Recycling 3C: Incineration gas phase + filtration	Spontaneously flammable in air (pyrophoric) Ensure blockage by combustion products does not give false indication of empty cylinder or system $Si_2H_6 + 3{,}5\ O_2 \rightarrow 2\ SiO_2 + 3\ H_2O$ (Method 3C)
051A	Ethane	C_2H_6	74-84-0	1: Recycling 3A: Direct combustion 3B: Combustion/incineration 4B: Direct discharge from container valve into fume cubicle or hood 4C: Controlled release through vent line 4D: Controlled dilution in forced air stream	Avoid plastics, rubber etc. with liquid. $C_2H_6 + 3{,}5\ O_2 \rightarrow 2\ CO_2 + 3\ H_2O$ (Methods 3A and 3B)
052	Ethyl acetylene	C_4H_6	107-00-6	1: Recycling 3A: Direct combustion 3B: Combustion/incineration	Avoid air suck back. Avoid copper and silver. Avoid plastics, rubber etc. with liquid. Use steel, brass with less than 70% copper. $C_4H_6 + 5{,}5\ O_2 \rightarrow 4\ CO_2 + 3\ H_2O$ (Methods 3A and 3B)

EIGA SDS	Usual Name	Chemical formula	CAS Registry Number	Disposal method	Key characteristics and operational and safety considerations
054	Ethyl amine	C_2H_7N	75-04-7	1: Recycling 2A: Direct discharge into simple scrubber 2B: Discharge into counterflow scrubber 2C: Discharge into solid-state adsorber 3C+2A/B: Incineration followed by discharge to scrubber	Avoid copper, nickel, tin, zinc Avoid plastics, rubber etc., with liquid. Use steel and PTFE $2\ C_2H_7N + 7{,}5\ O_2 \rightarrow 4\ CO_2 + N_2 + 7\ H_2O$ Control combustion conditions to minimise nitrogen dioxide production (Method 3C) $2\ C_2H_7N + H_2SO_4 \rightarrow 2\ C_2H_5NH_3^+ + SO_4^{2-}$ (Methods 2A and 2B) Adsorption on activated charcoal (Method 3C)
053	Ethyl methyl ether	C_3H_8O	540-67-0	1: Recycling 3A: Direct combustion 3B: Combustion/incineration	Avoid plastics, rubber etc., with liquid $C_3H_8O + 4{,}5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$ (Methods 3A and 3B)
055A	Ethylene	C_2H_4	74-85-1	1: Recycling 3A: Direct combustion	If temperature falls to less than 10 °C (50 °F), ensure liquid ethylene is not left in the cylinder or system $C_2H_4 + 3\ O_2 \rightarrow 2\ CO_2 + 2\ H_2O$ (Method 3A)
056	Ethylene oxide	C_2H_4O	75-21-8	1: Recycling 2B: Discharge into counterflow scrubber 3B: Combustion/incineration 3C: Incineration	Subject to exothermic self-decomposition and self-polymerisation Vapour can explode by spark, detonation, or heating greater than 440 °C (824 °F) Avoid suck back of water, acid or alkali, or other catalysts. Avoid magnesium and silver Avoid plastics, rubber etc., with liquid Use precleaned and dried steel and PTFE Ensure polymer blockage does not give false indication of emptied cylinder or system Absorption of ethylene oxide in a counterflow scrubber and its subsequent hydration to ethylene glycol. Reaction rate is a function of temperature in the presence of a catalyst, typically sulfuric acid. (Method 2B) $C_2H_4O + 2{,}5\ O_2 \rightarrow 2\ CO_2 + 2\ H_2O$ (Method 3B) Only diluted gas with approximately 10% ethylene oxide (Method 3C) Containers are commonly pressurised to 5 bar to 7 bar with nitrogen

EIGA SDS	Usual Name	Chemical formula	CAS Registry Number	Disposal method	Key characteristics and operational and safety considerations
057	Fluorine	F_2	7782-41-4	1: Recycling 2B: Discharge into counter flow scrubber 4B+2C: Dilution and discharge to solid-state adsorber	Use of a wet scrubber under certain conditions can generate oxygen difluoride (OF_2) Control the heat reaction by dilution and/or by cooling the solid-state adsorber Avoid grease and other combustible contaminants Use heavy gauge mild steel, nickel alloys, or Monel precleaned and passivated Introduce initially only small quantities until the system is passivated $6F_2 + 2Al_2O_3$ -> $4AlF_3 + 3O_2$ (Method 2C)
058	Fluoroethane	C_2H5_F	353-36-6	1: Recycling 3C+2B: High temperature incineration followed by scrubbing	Avoid plastics, rubber etc., with liquid. High temperature decomposition products are toxic.
059	Fluoromethane	CH_3F	593-53-3	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid High temperature decomposition products are toxic
060	Germane	GeH_4	7782-65-2	1: Recycling 2C: Discharge into solid-state adsorber 3C: Incineration gas phase + filtration	Spontaneously flammable in air (pyrophoric) Ensure blockage by combustion products does not give false indication of empty cylinder or system High temperature decomposition products are toxic $GeH_4 + 2\ O_2 \rightarrow GeO_2 + 2\ H_2O$ (Method 3C)
	Germanium tetrachloride	$GeCl_4$	10038-98-9	1: Recycling 2A: Direct discharge into simple scrubber 2B: Discharge into counterflow scrubber 2C: Discharge into solid-state adsorber	Avoid plastics, rubber etc., with liquid. Use heavy gauge mild steel. Ensure blockage by corrosion products does not give false indication of empty cylinder or system. $GeCl_4 + 2\ H_2O \rightarrow GeO_2 + 4\ HCl$ (Methods 2A and 2B) Adsorption on soda lime (Method 2C)
138	Germanium tetrafluoride	GeF_4	7783-58-6	1: Recycling 2B: Discharge into counterflow scrubber	$3\ GeF_4 + 2\ H_2O \rightarrow GeO_2 + 2\ H_2GeF_6$ (Method 2B)
Not listed	1,1,2-Trichloro-1,2,2-trifluoroethane (R113)	$C_2Cl_3F_3$	76-13-1	1: Recycling 3C+2B: High temperature incineration followed by scrubbing	Avoid plastics, rubber etc., with liquid
061A	Helium	He	7440-59-7	1: Recycling 4B: Direct discharge from container valve into fume cubicle or hood 4C: Controlled release through vent line 4D: Controlled dilution in forced air stream	

EIGA SDS	Usual Name	Chemical formula	CAS Registry Number	Disposal method	Key characteristics and operational and safety considerations
062	2H-Heptafluoropropane (R227ea)	C_3HF_7	431-89-0	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid
131	Hexafluoro-1,3-Butadiene	C_4F_6	685-63-2	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid
063	Hexafluoroacetone	C_3F_6O	684-16-2	1: Recycling 2B: Discharge into counterflow scrubber	Use nickel, Monel, stainless steel All equipment shall be precleaned and dry
065	Hexafluoroisobutene	$C_4H_2F_6$	382-10-5	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid
066	Hexafluoropropene (R1216)	C_3F_6	116-15-4	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber, etc., with liquid
067A	Hydrogen	H_2	1333-74-0	1: Recycling 3A: Direct combustion 4C: Controlled release through vent line 4D: Controlled dilution in forced air stream	Ignites very readily, flame barely visible $H_2 + 0,5\ O_2 \rightarrow H_2O$ (Method 3A)
068	Hydrogen bromide	HBr	10035-10-6	1: Recycling 2C: Discharge into solid-state adsorber 4C+2A/B: Controlled release followed by discharge to scrubber	Ensure blockage by corrosion products does not give false indication of empty cylinder or system Use Monel, nickel and its alloys, heavy gauge mild steel with moist gas Avoid suck back of water $HBr + OH^- \rightarrow Br^- + H_2O$ (Methods 2A and 2B) Adsorption on soda lime (Method 2C)
069	Hydrogen chloride	HCl	7647-01-0	1: Recycling 2C: Discharge into solid-state adsorber 4C+2A/B: Controlled release followed by discharge to scrubber	Ensure blockage by corrosion products does not give false indication of empty cylinder or system Use Monel, nickel and its alloys, heavy gauge mild steel if moist Avoid suck back of water $HCl + OH^- \rightarrow Cl^- + H_2O$ (Methods 2A and 2B) Adsorption on soda lime (Method 2C)

EIGA SDS	Usual Name	Chemical formula	CAS Registry Number	Disposal method	Key characteristics and operational and safety considerations
Not listed	Hydrogen cyanide	HCN	74-90-8	1: Recycling 2B: Discharge into counterflow scrubber 3C+2B: Incineration followed by discharge into counterflow scrubber	Fast acting, irreversible, systemic poison Caution should be exercised when dealing with pure hydrogen cyanide because of its instability and the possibility of an uncontrolled reaction leading to explosion Avoid suck back of water and catalyst acid or alkalis that promote polymerisation (explosion possible) Use stainless steel, Monel, nickel and its alloys, and PTFE $2\ HCN + 4\ OH^- + 5\ OCl^- \rightarrow N_2 + 2\ CO_3^{2-} + 5\ Cl^- + 3\ H_2O$ (pH > 11) (Method 2B) Burning with hot efficient flame, controlled combustion conditions to minimise nitrogen dioxide formation $2\ HCN + 2{,}5\ O_2 \rightarrow 2\ CO_2 + N_2 + H_2O$ (Method 3C)
070	Hydrogen fluoride	HF	7664-39-3	1: Recycling 2C: Discharge into solid-state adsorber 4C+2B: Controlled release followed by discharge to scrubber	Attacks and penetrates the skin, causes delayed severe deep-seated necrosis Ensure blockage by corrosion products does not give false indication of empty cylinder or system Use heavy gauge mild steel, copper and PTFE $HF + OH^- \rightarrow F^- + H_2O$ (Method 2B) Adsorption on soda lime (Method 2C)
071	Hydrogen iodide	HI	10034-85-2	1: Recycling 2C: Discharge into solid-state adsorber 4C+2A/B: Controlled release followed by discharge to scrubber	Ensure blockage by corrosion products does not give false indication of empty cylinder or system Use Monel, nickel and its alloys, heavy gauge mild steel if moist Avoid suck back of water $HI + OH^- \rightarrow I^- + H_2O$ (Methods 2A and 2B) Adsorption on soda lime (Method 2C)
072	Hydrogen selenide	H_2Se	7783-07-5	1: Recycling 3C+2B: Incineration followed by discharge into counterflow scrubber 2C: Discharge into solid-state adsorber	Elemental selenium can be present in cylinders and lines High temperature decomposition products are toxic $H_2Se + 1{,}5\ O_2 \rightarrow SeO_2 + H_2O$ (Method 3C) $SeO_2 + H_2O \rightarrow H_2SeO_3$ (Method 2B) Adsorption on activated charcoal or copper sulphate treated silica gel (Method 2C)
073	Hydrogen sulphide	H2S	7783-06-4	1: Recycling 2B: Discharge into counterflow scrubber 3C+2B: Incineration followed by discharge into counterflow scrubber 2C: Discharge into solid-state adsorber	Use aluminium, stainless steel (brass with dry gas) and PTFE $H_2S + OH^- + 4\ OCl^- \rightarrow HSO_4^- + 4\ Cl^- + H_2O$ (Method 2B) $H_2S + 1{,}5\ O_2 \rightarrow SO_2 + H_2O$ (Method 3C) $SO_2 + 2\ OH^- + OCl^- \rightarrow SO_4^{2--} + Cl^- + H_2O$ (Method 2B) Adsorption on soda lime (Method 2C)

EIGA SDS	Usual Name	Chemical formula	CAS Registry Number	Disposal method	Key characteristics and operational and safety considerations
074	Hydrogen telluride	H_2Te	7783-09-7	1: Recycling 3C+2B: Incineration followed by discharge into counterflow scrubber 2C: Discharge into solid-state adsorber	Elemental tellurium can be present in cylinders and lines. Use Monel, nickel and its alloys, stainless steel or heavy gauge mild steel $H_2Te + 1,5\ O_2 \rightarrow TeO_2 + H_2O$ (Method 3C) $TeO_2 + 2\ OH^- \rightarrow TeO_3^{2-} + H_2O$ (Method 2B) Adsorption on activated charcoal or copper sulphate treated silica gel (Method 2C)
Not listed	Iodine pentafluoride	IF_5	7783-66-6	1: Recycling 3C+2B: Incineration followed by discharge into counterflow scrubber	Avoid grease and all other combustible contaminants Use Monel, nickel and its alloys, heavy gauge mild steel, and PTFE. All equipment to be precleaned and passivated Reacts violently with water Ensure that blockage by corrosion products does not give false indication of empty cylinder or system Introduce initially only small quantities until one the system is passivated Unwanted residual gases shall be securely contained and safely transported to a facility properly equipped and staffed for disposal
077A	Krypton	Kr	7439-90-9	1: Recycling 4B: Direct discharge from container valve into fume cubicle or hood 4C: Controlled release through vent line 4D: Controlled dilution in forced air stream	
078A	Methane	CH_4	74-82-8	1: Recycling 3A: Direct combustion 4C: Controlled release through vent line	$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$ (Method 3A)
079	3-Methyl 1-butene	C_5H_{10}	563-45-1	1: Recycling 3A: Direct combustion 3B: Combustion/incineration	Avoid plastics, rubber, etc., with liquid Avoid suck back of air $C_5H_{10} + 7,5\ O_2 \rightarrow 5\ CO_2 + 5\ H_2O$ (Methods 3A and 3B)
081	Methyl acetylene	C_3H_4	74-99-7	1: Recycling 3A: Direct combustion 3B: Combustion/incineration	Subject to exothermic self- decomposition, if not stabilised Avoid copper and silver Avoid plastics, rubber, etc., with liquid Use steel and PTFE Avoid suck back of air $C_3H_4 + 4\ O_2 \rightarrow 3\ CO_2 + 2\ H_2O$ (Methods 3A and 3B)

EIGA SDS	Usual Name	Chemical formula	CAS Registry Number	Disposal method	Key characteristics and operational and safety considerations
082	Methyl amine	CH_5N	74-89-5	1: Recycling 2B: Discharge into counterflow scrubber 2C: Discharge into solid-state adsorber 3A: Direct combustion 3C+2B: Incineration followed by discharge into counterflow scrubber	$2\ CH_5N + 4{,}5\ O_2 \rightarrow 2\ CO_2 + N_2 + 5\ H_2O$ Control combustion conditions to minimise nitrogen dioxide production (Methods 3A and 3C) $2\ CH_5N + H_2SO_4 \rightarrow\ 2\ CH_3NH_3^+ + SO_4^{2-}$ (Method 2B) Adsorption on activated charcoal (Method 2C)
083	Methyl mercaptan	CH_4S	74-93-1	1: Recycling 2C: Discharge into solid-state adsorber 3C+2B: Incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber, etc., with liquid $CH_4S + 3\ O_2 \rightarrow\ CO_2 + SO_2 + 2\ H_2O$ (Method 3C) $SO_2 + 2\ OH^- \rightarrow SO_3^{2-} + H_2O$ (Method 2B) Adsorption on activated charcoal (Method 2C)
084	Methyl silane	CH_3SiH_3	992-94-9	1: Recycling 3C: Incineration gas phase + filtration	Ensure that combustion product blockage does not give false indication of empty cylinder or system $CH_3SiH_3 + 3{,}5\ O_2 \rightarrow SiO_2 + CO_2 + 3\ H_2O$ (Method 3C)
080	Methyl vinyl ether	C_3H_6O	107-25-5	1: Recycling 3A: Direct combustion 3B: Combustion incineration	Avoid copper and silver if acetylene is present or as an impurity Avoid plastics, rubber etc., with liquid $C_3H_6O + 4\ O_2 \rightarrow 3\ CO_2 + 3\ H_2O$ (Methods 3A and 3B)
	Natural gas	Mixture		1: Recycling 3A: Direct combustion 4C: Controlled release through vent line	$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$ (Method 3A)
086A	Neon	Ne	7440-01-9	1: Recycling 4B: Direct discharge from container valve into fume cubicle or hood 4C: Controlled release through vent line 4D: Controlled dilution in forced air stream	
088	Nitric oxide	NO	10102-43-9	1: Recycling 2B: Discharge into counterflow scrubber	Use stainless steel and PTFE in presence of oxygen and moisture Oxidising scrubbing solution (permanganate, hypochlorite) is required for high efficiency After oxidation with air: $2\ NO_2 + 2\ OH^- + OCl^- \rightarrow 2\ NO_3^- + Cl^- + H_2O$ (Method 2B)
089A	Nitrogen	N_2	7727-37-9	1: Recycling 4A: Direct discharge from container valve 4B: Direct discharge from container valve into fume cubicle or hood	

EIGA SDS	Usual Name	Chemical formula	CAS Registry Number	Disposal method	Key characteristics and operational and safety considerations
090	Nitrogen dioxide (Dinitrogen tetroxide)	NO_2 (N_2O_4)	10102-44-0	1: Recycling 2B: Discharge into counterflow scrubber 2C: Discharge into solid-state adsorber	Avoid plastics, rubber, etc. Use stainless steel and PTFE $2 NO_2 + 2 OH^- + OCl^- \rightarrow 2 NO_3^- + Cl^- + H_2O$ (Method 2B) Adsorption on soda lime (Method 2C)
091	Nitrogen trifluoride	NF_3	7783-54-2	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Powerful oxidising agent at elevated temperatures Avoid oil, grease and other combustible contaminants Avoid plastics, rubber, etc. Use other precleaned common materials, PTFE, PCTFE
Not listed	Nitrogen trioxide	N_2O_3	10544-73-7	1: Recycling 2B: Discharge into counterflow scrubber	Avoid plastics, rubber etc. Use stainless steel and PTFE. $N_2O_3 + 2 OH^- \rightarrow 2 NO_2^- + H_2O$ (Method 2B)
092	Nitrosyl chloride	$NOCl$	2696-92-6	1: Recycling 2B: Discharge into counterflow scrubber	Use nickel, Monel, tantalum, lead, heavy gauge mild steel $NOCl + 2 OH^- + OCl^- \rightarrow NO_3^- + 2 Cl^- + H_2O$ (Method 2B)
093A	Nitrous oxide	N_2O	10024-97-2	1: Recycling 4A/B/C: Controlled release to atmosphere: for small quantities (for example, in mixtures) or in emergencies	Avoid oil and grease and other combustible contaminants Avoid plastics, rubber etc., with liquid
094	Octafluorobutene (R1318)	C_4F_8	360-89-4	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber, etc., with liquid
095	Octafluorocyclobutane (RC318)	C_4F_8	115-25-3	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid
	Octafluorocyclopentene	C_5F_8	559-40-0	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid
096	Octafluoropropane (R218)	C_3F_8	76-19-7	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid
132	Octafluorotetrahydrofuran	C_4F_8O	773-14-8	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid
097A	Oxygen	O_2	7782-44-7	1: Recycling 4A: Direct discharge from container valve 4C: Controlled release through vent line	Avoid oil and grease and other combustible contaminants All materials need to be cleaned for oxygen service Avoid local oxygen enrichment

EIGA SDS	Usual Name	Chemical formula	CAS Registry Number	Disposal method	Key characteristics and operational and safety considerations
Not listed	Pentacarbonyl iron	$Fe(CO)_5$	13463-40-6	1: Recycling 2C: Discharge into solid-state adsorber 3B: Combustion/incineration 3C: Incineration	Spontaneously flammable in air (pyrophoric) Check for high pressure propellant and dip tube May be dissolved in a combustible solvent $2\ Fe(CO)_5 + 6.5\ O_2 \rightarrow Fe_2O_3 + 10\ CO_2$ (Methods 3B and 3C) Adsorption on activated charcoal (Method 2C)
137	Pentafluoroethane	C_2HF_5	354-33-6	1: Recycling 3C+2B: High temperature incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid
099	Phosgene	$COCl_2$	75-44-5	1: Recycling 2B: Discharge into counterflow scrubber	Ensure blockage by corrosion products does not give false indication of empty cylinder system Avoid plastics, rubber etc., with liquid Use Monel, stainless steel, heavy gauge mild steel and PTFE $COCl_2 + 4OH^- = CO_3^{2-} + 2Cl^- + 2H_2O$ (Method 2B)
100	Phosphine	PH_3	7803-51-2	1: Recycling 3C+2B: Incineration followed by discharge into counterflow scrubber	Spontaneously flammable in air (pyrophoric) $2\ PH_3 + 4\ O_2 \rightarrow P_2O_5 + 3\ H_2O$ (Method 3C) $P_2O_5 + 3\ H_2O \rightarrow 2\ H_3PO_4$ (Method 2B) $PH_3 + 4\ OCl^- \rightarrow H_3PO_4 + 4\ Cl^-$ (Method 2B)
101	Phosphorus pentafluoride	PF_5	7647-19-0	1: Recycling 2B: Discharge into counterflow scrubber 2C: Discharge into solid-state adsorber	Use nickel, Monel, heavy gauge mild steel Use hard rubber, PVC for moist gas $PF_5 + 4H_2O \rightarrow H_3PO_4 + 5\ HF$ (Method 2B) Adsorption on soda lime (Method 2C)
102	Phosphorus trifluoride	PF_3	7783-55-3	1: Recycling 2B: Discharge into counterflow scrubber	Use alkaline scrubbing solution to ensure rapid hydrolysis $PF_3 + 6\ OH^- \rightarrow PO_3^{3-} + 3\ F^- + 3\ H_2O$ (Method 2B)
103	1,2-Propadiene	C_3H_4	463-49-0	1: Recycling 3A: Direct combustion 3B: Combustion/incineration	Subject to self-polymerisation Guard against polymer blockage, check that content is stable (i.e., that no temperature rise of cylinder) Avoid plastics, rubber, etc., with liquid $C_3H_4 + 4\ O_2 \rightarrow 3\ CO_2 + 2\ H_2O$ (Methods 3A and 3B)
104	Propane (R290)	C_3H_8	74-98-6	1: Recycling 3A: Direct combustion 3B: Combustion/incineration	Avoid plastics, rubber etc. with liquid $C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$ (Methods 3A and 3B)
105	Propylene (R1270)	C_3H_6	115-07-1	1: Recycling 3A: Direct combustion 3B: Combustion/incineration	Avoid plastics, rubber etc., with liquid $C_3H_6 + 4{,}5\ O_2 \rightarrow 3\ CO_2 + 3\ H_2O$ (Methods 3A and 3B)

EIGA SDS	Usual Name	Chemical formula	CAS Registry Number	Disposal method	Key characteristics and operational and safety considerations
Not listed	Propylene oxide	C_3H_6O	75-56-9	1: Recycling 3B: Combustion/incineration	Subject to exothermic self-decomposition and self-polymerisation Vapour can explode by spark, detonation, and or heating Avoid silver Avoid plastics, rubber etc., with liquid Use precleaned and dried steel and PTFE Avoid suck back of water, acid, alkali, or other catalysts. Ensure polymer blockage does not give false indication of empty cylinder or system $C_3H_6O + 4\ O_2 \rightarrow 3\ CO_2 + 3\ H_2O$ (Method 3B)
106	Selenium hexafluoride	SeF_6	7783-79-1	1: Recycling 3C+2B: Incineration followed by discharge to scrubber	SeF_6 + fuel + $O_2 \rightarrow SeO_2 + 6\ HF$ + + … (Method 3C) $HF + OH^- \rightarrow F^- + H_2O$ $SeO_2 + OH^- \rightarrow SeO^- + H_2O$ (Method 2B)
107	Silane	SiH_4	7803-62-5	1: Recycling 3C: Incineration gas phase + filtration	Spontaneously flammable in air (pyrophoric) Ensure blockage by combustion products goes not give false indication of empty cylinder or system $SiH_4 + 2\ O_2 \rightarrow SiO_2 + 2\ H_2O$ (Method 3C)
Not listed	Silicon tetrachloride	$SiCl_4$	10026-04-7	1: Recycling 2A: Direct discharge into simple scrubber 2B: Discharge into counterflow scrubber 2C: Discharge into solid-state adsorber	Avoid plastics, rubber etc., with liquid Use heavy gauge mild steel Ensure blockage by corrosion products does not give false indication of empty cylinder or system $SiCl_4 + 2\ H_2O \rightarrow SiO_2 + 4\ HCl$ (Methods 2A and 2B) Adsorption on soda lime (Method 2C)
108	Silicon tetrafluoride	SiF_4	7783-61-1	1: Recycling 2B: Discharge into counterflow scrubber	$3\ SiF_4 + 2\ H_2O \rightarrow SiO_2 + 2\ H_2SiF_6$ (Method 2B)
109	Stibine	SbH_3	7803-52-3	1: Recycling 2B: Discharge into counterflow scrubber 2C: Discharge into solid-state adsorber 4B+2B: Dilution and discharge into counterflow scrubber	Spontaneously flammable in air (pyrophoric) Use iron or steel Elemental stibine can be present in cylinders or lines $SbH_3 + 4\ H_2O \rightarrow SbO_4^{3-} + 11\ H^+ + 8\ e^-$ (Method 2B) The following oxidants can be used: permanganate or hypo-chlorite Adsorption on activated charcoal or on copper sulphate treated silica gel $3\ CuSO_4 + 2\ SbH_3 \rightarrow Cu_3Sb_2 + 3\ H_2SO_4$ (Method 2C)
112	Sulfuryl difluoride	F_2O_2S	2699-79-8	1: Recycling 3C+2B: High temperature Incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid.

EIGA SDS	Usual Name	Chemical formula	CAS Registry Number	Disposal method	Key characteristics and operational and safety considerations
113	Sulphur dioxide	SO_2	7446-09-5	1: Recycling 2A: Direct discharge into simple scrubber 2B: Discharge into counterflow scrubber 2C: Discharge into solid-state adsorber	$SO_2 + 2\ OH^- + Ocl^- \rightarrow SO_4^{2-} + Cl^- + H_2O$ (Methods 2A and 2B) Adsorption on soda lime (Method 2C)
110	Sulphur hexafluoride	SF_6	2551-62-4	1: Recycling 4A: Direct discharge from container valve 4B: Direct discharge from container valve into fume cubicle or hood 4C: Controlled release through vent line 4D: Controlled dilution in forced air stream	
111	Sulphur tetrafluoride	SF_4	7783-60-0	1: Recycling 2B: Discharge into counterflow scrubber 2C: Discharge into solid-state adsorber	Avoid plastics, rubber etc., with liquid $SF_4 + 3\ Ca(OH)_2 \rightarrow 2\ CaF_2 + CaSO_4 + H_2 + 2\ H_2O$ (Method 2B) Adsorption on $Al(OH)_3$ or soda lime (Method 2C)
Not listed	Tetracarbonyl nickel	$Ni(CO)_4$	13463-39-3	1: Recycling 2C: Discharge into solid-state adsorber 3B: Combustion/incineration	Check for high pressure propellant and dip tube. May be dissolved in a combustible solvent $Ni(CO)_4 + 2,5\ O_2 \rightarrow NiO + 4\ CO_2$ (Method 3B) Adsorption on activated charcoal (Method 2C)
	Tetrachloromethane	CCl_4	56-23-5	1: Recycling 3C+2B: High temperature Incineration followed by discharge into counterflow scrubber	Incineration under certain conditions can generate phosgene
133	Tetrafluoroethane (R134a)	$C_2H_2F_4$	811-97-2	1: Recycling 3C+2B: High temperature Incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid
114	Tetrafluoroethylene (R1114)	C_2F_4	116-14-3	1: Recycling 3C+2B: High temperature Incineration followed by discharge into counterflow scrubber	Subject to violent self-polymerisation Ensure that blockage by polymerisation products does not give false indication of empty cylinder or system. Avoid PTFE

EIGA SDS	Usual Name	Chemical formula	CAS Registry Number	Disposal method	Key characteristics and operational and safety considerations
Not listed	Tetrafluorohydrazine	N_2F_4	10036-47-2	1: Recycling 4B+2B: Dilution and discharge into counterflow scrubber	Explosive self-decomposition possible with heat or shock (pressurised gas) Do not strike or hammer pressurised container Ensure blockage by corrosion products does not give false indication of empty cylinder or system Avoid grease and other combustible contaminants Use heavy gauge mild steel, nickel alloys, or Monel precleaned and passivated Introduce initially only small quantities until the system is passivated $N_2F_4 + O_2 + 2\ H_2O^{\text{(moist air)}} \rightarrow 2\ NO_2 + 4\ HF\ (\rightarrow 2\ NO + 4\ F^-)$ $2\ NO_2 + 4\ HF\ (\rightarrow 2\ NO + 4\ F^-)$ (Method 2B)
116	Tetrafluoromethane (R14)	CF_4	75-73-0	1: Recycling 3C+2B: High temperature Incineration followed by discharge into counterflow scrubber	
Not listed	Trichlorofluoromethane (R11)	CCl_3F	75-69-4	1: Recycling 3C+2B: High temperature Incineration followed by discharge into counterflow scrubber	Incineration under certain conditions can generate phosgene
Not listed	Trichlorosilane	$SiHCl_3$	10025-78-2	1: Recycling 2B: Discharge into counterflow scrubber 2C: Discharge into solid-state adsorber	Ensure that blockage by corrosion/combustion products does not give false indication of empty cylinder or system Use stainless steel, iron, steel, or borosilicate glass Avoid contact with oxidising materials Avoid flowing liquid through nonelectrically conductive lines $SiHCl_3 + 2\ NaOH + H_2O \rightarrow Na_2SiO_3 + 3\ HCl + H_2$ (Methods 2A and 2B)
118	Trifluoroethane (R143a)	$C_2H_3F_3$	420-46-2	1: Recycling 3C+2B: High temperature Incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid
119	Trifluoromethane (R23)	CHF_3	75-46-7	1: Recycling 3C+2B: High temperature Incineration followed by discharge into counterflow scrubber	Avoid plastics, rubber etc., with liquid

EIGA SDS	Usual Name	Chemical formula	CAS Registry Number	Disposal method	Key characteristics and operational and safety considerations
122	Trimethylamine	C_3H_9N	75-50-3	1: Recycling 2B: Discharge into counterflow scrubber 2C: Discharge into solid-state adsorber 3C+2A: Incineration followed by direct discharge to scrubber	Avoid copper, nickel, tin, zinc Avoid plastics, rubber etc., with liquid Use steel and PTFE $2\ C_3H_9N + 10{,}5\ O_2 \rightarrow 6\ CO_2 + 9\ H_2O + N_2$ Control to minimise nitrogen dioxide production (Methods 3A and 3C) $2\ (CH_3)_3N + H_2SO_4 \rightarrow 2\ (CH_3)_3NH^+ + SO_4^{2-}$ (Methods 2A and 2B) Adsorption on activated charcoal (Method 2C)
138	Trimethylboron	$B(CH_3)_3$	593-90-8	1: Recycling 2B: Discharge into counterflow scrubber 3B+2C: Incineration followed by discharge into counterflow scrubber	$B(CH_3)_3 + {}_6H2O$-> $3CH_3OH + 3H_2 + H_3BO_3$ (Method 2B) Voluminous cloud of boron trioxide can be produced Beware for blockage of pipework/nozzles by boron trioxide
121	Trimethylsilane	$C_3H_{10}Si$	993-07-7	1: Recycling 3C: Incineration gas phase + filtration	Ensure that blockage by combustion products does not give false indication of empty cylinder or system $(CH_3)_3SiH + 6{,}5\ O_2 \rightarrow 3\ CO_2 + SiO_2 + 5\ H_2O$
123	Tungsten hexafluoride	WF_6	7783-82-6	1: Recycling 2B: Discharge into counterflow scrubber 2C: Discharge into solid-state adsorber	Avoid plastic, rubber, etc., with liquid. $WF_6 + 8\ KOH \rightarrow K_2WO_4 + 6\ KF + 4\ H_2O$ (Method 2B) $WF_6 + 4\ CaO \rightarrow CaWO_4 + 3\ CaF_2$ or $3\ WF_6 + 4\ Al_2O_3 \rightarrow Al_2(WO_4)_3 + 6\ AlF_3$ (Examples of Method 2C)
124	Vinyl bromide	C_2H_3Br	593-60-2	1: Recycling 3C+2B: Incineration followed by discharge into counterflow scrubber	Avoid copper and silver if acetylene is present or as an impurity Avoid plastics, rubber etc., with liquid $C_2H_3Br + 2{,}5\ O_2 \rightarrow 2\ CO_2 + HBr + H_2O$ (Method 3C) $HBr + OH^- \rightarrow Br^- + H_2O$ (Method 2B)
125	Vinyl chloride	C_2H_3Cl	75-01-4	1: Recycling 3C+2B: Incineration followed by discharge into counterflow scrubber	Avoid copper and silver if acetylene is present or as an impurity Avoid plastics, rubber etc. with liquid $C_2H_3Cl + 2{,}5\ O_2 \rightarrow 2\ CO_2 + HCl + H_2O$ (Method 3C) $HCl + OH^- \rightarrow Cl^- + H_2O$ (Method 2B)
126	Vinyl fluoride	C_2H_3F	75-02-5	1: Recycling 3C+2B: Incineration followed by discharge into counterflow scrubber	Avoid copper and silver if acetylene is present or as an impurity Avoid plastics, rubber etc., with liquid $C_2H_3F + 2{,}5\ O_2 \rightarrow 2\ CO_2 + HF + H_2O$ (Method 3C) $HF + OH^- \rightarrow F^- + H_2O$ (Method 2B)
127	Xenon	Xe	7440-63-3	1: Recycling 4B: Direct discharge from container valve into fume cubicle or hood	