CODE OF PRACTICE
NITROGEN TRIFLUORIDE

AIGA 029/18

Revision of AIGA 029/10

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CODE OF PRACTICE NITROGEN TRIFLUORIDE

As part of a programme of harmonization of industry standards, the Asia Industrial Gases Association (AIGA) publication, AIGA 029, *Code of Practice, Nitrogen trifluoride*, jointly produced by members of the International Harmonization Council and originally published by the European Industrial Gases Association (EIGA) as Doc 92, *Nitrogen trifluoride.*

This publication is intended as an international harmonized publication for the worldwide use and application by all members of Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), European Industrial Gases Association, (EIGA), and Japan Industrial and Medical Gases Association (JIMGA). Each association's technical content is identical, except for regional regulatory requirements and minor changes in formatting and spelling.

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Amendments to AIGA 029/10

Section	Description
3.1	Harmonised AIGA publication terminology definitions reviewed
3.2	Several technical definitions added
4	Tables 1 and 2 updated with US units
6.2	Reference to ISO 11114-1 added
7.2.1	Reference to ISO 11114-1 added
Other sections	Editorial amendments without change of the technical content.

Note: Technical changes from the previous edition are underlined

1 Introduction

Nitrogen trifluoride is an oxidizing compressed gas that is used in a number of applications as a fluorinating agent. It is this property that makes it valuable as a nonreactive source of fluorine for etching and cleaning applications. The active fluorine is released only if sufficient energy is applied. Once initiated, the reaction is self-propagating and presents a hazard for materials that are incompatible with fluorine, for example, flammable gas and metals.

Nitrogen trifluoride can be safely handled if equipment is properly designed and handling precautions are taken.

NOTE: This publication shall be used in conjunction with AIGA 083 *Disposal of Gases*, AIGA 004, *Handling Gas Container Emergencies*, and AIGA 021, *Oxygen Pipeline and Piping Systems* [1, 2, 3][1].

2 Scope and purpose

Because of its widespread use and its potential for mishandling, this publication has been written and is intended for suppliers, distributors, and users of nitrogen trifluoride and its handling equipment. This publication provides a description of the potential hazards involved in handling nitrogen trifluoride and the guidelines to be taken to minimise risk potential.

The manufacture, purification, and analysis of nitrogen trifluoride are beyond the scope of this publication, although the general guidance given is also relevant to these processes.

Appendix A of this publication is an audit checklist.

3 Definitions

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

3.1 Publication terminology

3.1.1 Shall

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

3.1.2 Should

Indicates that a procedure is recommended.

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

3.1.3 May

Indicates that the procedure is optional.

3.1.4 Will

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

3.1.5 Can

Indicates a possibility or ability.

3.2 Technical definitions

3.2.1 Auto-ignition temperature

Temperature at which a substance will spontaneously ignite in a specified oxidant at a given pressure.

3.2.2 Container

3.2.2.1 Bundle of cylinders

Arrangement of cylinders into a cluster where the cylinders are confined into a grouping or arrangement with a strapping or frame system and connections are made to a common manifold. Also known as cylinder packs.

3.2.2.2 Cylinder

Seamless pressure vessel having a nominal water capacity up to 50 L.

3.2.2.3 International Organization for Standardization (ISO) module

Multi-modal assembly of cylinders, tubes, or bundles of cylinders that are interconnected by a manifold and assembled within a framework.

NOTE The ISO module includes service equipment and structural equipment necessary for the transport of gases. The frame of an ISO module and its corner castings are specially designed and dimensioned for use in multi-modal transportation service on container ships, special highway chassis, and container-on-flatcar railroad equipment. An ISO module may also be referred to in regulations as a multiple-element gas container (MEGC) and its' equivalent.

3.2.2.4 Multiple-element gas container (MEGC)

Assembly of cylinders, tubes, or bundles of cylinders that are interconnected by a manifold and are assembled within a framework.

NOTE The MEGC module includes service equipment and structural equipment necessary for the transport of gases.

3.2.2.5 Packages greater than 50 L

Any individual or manifolded collection of seamless pressure vessel(s) having a collective nominal water capacity greater than 50 L.

NOTE These can include an ISO module, MEGCs, tubes, tube trailers, cylinder packs, nominal 450 L (ton tank), or other packages as defined by regulations or codes.

3.2.2.6 Ton tank

Seamless pressure vessel having a nominal water capacity of 450 L.

3.2.2.7 Tube

Seamless pressure vessel having a nominal water capacity exceeding 150 L but not more than 3000 L.

3.2.2.8 Tube trailer

Truck or semitrailer on which a number of tubes have been mounted and manifolded into a common piping system.

3.2.3 Filling ratio

Ratio of the mass of a gas introduced in a container to the mass of water at 15 °C (59° F) that would fill the same container fitted ready for use. Also known as fill density, filling factor, maximum fill degree, or maximum fill pressure.

NOTE The water capacity stamped on the cylinder may apply to the minimum water capacity designed without internal fittings, in which case the net water capacity shall be determined.

3.2.4 Gas

Gas or gas under pressure as defined in the United Nations (UN) *Recommendations on the Transport of Dangerous Goods, Model Regulations* and in *Globally Harmonized System of Classification and Labelling of Chemicals* (GHS) [4, 5].

A gas is a substance that (a) At 50 °C has a vapour pressure greater than 300 kPa; or (b) is completely gaseous at 20 °C at a standard pressure of 101.3 kPa.

3.2.5 Gas cabinet

Fully enclosed, non-combustible enclosure used to provide an isolated environment for compressed gas cylinders in storage or use.

NOTE Doors and access ports for exchanging cylinders and accessing pressure regulating controls are allowed to be included.

3.2.6 Oxipotential

Oxidizing power of a gas compared to that of oxygen given as a dimensionless number where oxygen = 1. See ASTM STP 1395, *Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres* [6].

3.2.7 Passivation

Pre-treatment method to allow the formation of a self-limiting protective fluoride film on the surface of the material in a controlled manner that limits any additional fluorine reaction.

3.2.8 Risk assessment

Documented assessment of the risks of a specific operation to personnel and the environment. This process usually takes into account safety controls inherent in equipment, operating procedures, and personal protective equipment (PPE) provided. Sometimes, it may be deemed necessary to improve operational safety controls after undertaking a risk assessment.

3.2.9 Swarf

Small strips or particles of metal that can arise from machining operations.

4 Properties of nitrogen trifluoride

4.1 Nitrogen trifluoride identification and physical properties

Table 1 shows properties of nitrogen trifluoride.

Table 1—Physical properties of nitrogen trifluoride

Property	SI Units	U.S. Units
Chemical formula	NF_3	
CAS number	7783-54-2	
EC number	232-007-1	
UN number	UN 2451	
Molecular weight	71	71
Melting point at 1 atm	–206.8 °C	–340.2 °F
Latent heat of fusion at melting point	1.34 cal/g	2.41 Btu/lb
Boiling point at 1 atm	–129.1 °C	–200.3 °F
Density of the liquid at boiling point	1538 kg/m^3	96.01 lb/ft^3
Density of the gas at 21.1 °C (70 °F) and 1 atm (air = 1)	2.95 kg/m^3	0.1843 lb/ft^3
Specific gravity of the gas at 21.1 °C (70 °F) and 1 atm (air = 1)	2.46	2.46
Specific volume of the gas 21.1 °C (70 °F) and 1 atm (air = 1)	0.337 m^3/ kg	5.43 ft^3/lb
Latent heat of vapourization at boiling point	162 kJ/kg	70.1 Btu/lb
Critical temperature	–39.2 °C	–38.5 °F
Critical pressure	4460 kPa, abs	646.9 psia
Critical density	562.3 kg/m^3	35.1 lb/ft^3
Heat capacity at 25 °C (77 °F)	0.1794 kcal/(kg • K)	0.0428 Btu/(lb • °F)
Entropy at 25 °C (77 °F) and 1 atm	–0.877 kcal/(kg • K)	– 0.471 Btu/(lbm • R)
Enthalpy at 25 °C (77 °F) and 1 atm	–29.8 kcal/mol	–800.39 Btu/lbm

4.2 Chemical properties

Nitrogen trifluoride is a stable, slightly toxic (see 4.3), oxidizing gas. Nitrogen trifluoride is a colourless and essentially odourless gas. At lower purities of nitrogen trifluoride, there can be a mouldy smell.

Oxipotential: 1.6 [6].

Ignition temperatures of some metals in nitrogen trifluoride at 1 bar and 7 bar are as follows:

	Copper	Iron	Nickel
1 bar	550 °C (1022 °F)	817 °C (1503 °F)	1187 °C (2168 °F)
7 bar	475 °C (887 °F)	612 °C (1133 °F)	967 °C (1772 °F)

NOTE In Europe, nitrogen trifluoride is classified according to the *Classification, Labelling and Packaging* (CLP) Regulation as Ox. Gas 1, H270; Press. Gas (Liq.), H280; Acute Tox. 4 (Inhalation: gas), H332; STOT RE 2, H373 (see also Annex 2) [7].

NOTE For classification of nitrogen trifluoride in the U.S., see CGA C-7, *Guide to Classification and Labeling of Compressed Gases* [8].

4.3 Toxicology

Established levels of nitrogen trifluoride exposure vary between countries and agencies. Refer to the governing agency in the country where nitrogen trifluoride is being used. See Table 2 for examples of established maximum limits of nitrogen trifluoride exposure to personnel used in the industrial gas industry.

NOTE Thermal decomposition of nitrogen trifluoride can be very toxic.

For more information, see the gas supplier's safety data sheet (SDS) [11].

Table 2—Exposure limits for nitrogen trifluoride

Occupational Safety and Health Administration (OSHA) Time Weighted Average (TWA) — Permissible Exposure Limit (PEL) [9]	10 ppm (29 mg/m^3)
National Institute for Occupational Safety and Health (NIOSH) recommended exposure limit (REL) – TWA [10]	10 ppm (29 mg/m^3)
NIOSH Immediate danger to life and health (IDLH) [10]	1000 ppm
LC_{50} (1-hr rat) [12]	6700 ppm
Emergency Exposure Level (EEL) [13]	≥ 22 500 ppm x min
Acute Exposure Guideline Levels (AEGLs) [14]	
AEGL-1 (30 minutes)	400 ppm
AEGL-2 (30 minutes)	1100 ppm
AEGL-3 (30 minutes)	1700 ppm

NOTES

1 OSHA limits are the legal exposure limits allowed by U.S. law and are enforceable.

2 NIOSH limits are recommended values and are not enforceable by law.

3 AEGL-1 is the airborne concentration (expressed as parts per million or milligrams per cubic meter [ppm or mg/m^3] of a substance above which it is predicted that the general population, including susceptible individual, could experience notable discomfort, irritation, or certain asymptomatic, non-sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.

AEGL-2 is the airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individual, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.

AEGL-3 is the airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience life threatening health effects or death.

4 In Asia, supplier safety data sheets (SDS) shall be consulted to find the applicable regulatory exposure limits in the different Asian countries, where determined.

4.4 Environmental issues

Solubility in water at 20 °C, 1 bara	61 mg/l
Lifetime in atmosphere	740 years
Global warming potential (carbon dioxide = 1)	17200

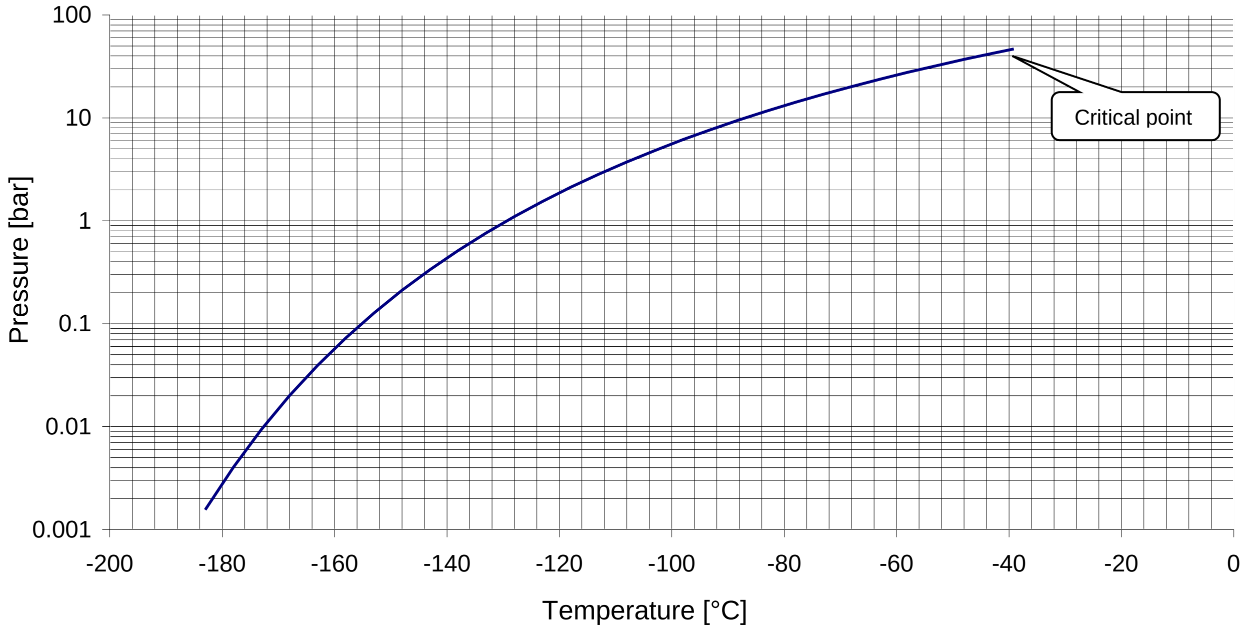

Figure 1—Vapour pressure curve (SI Units)

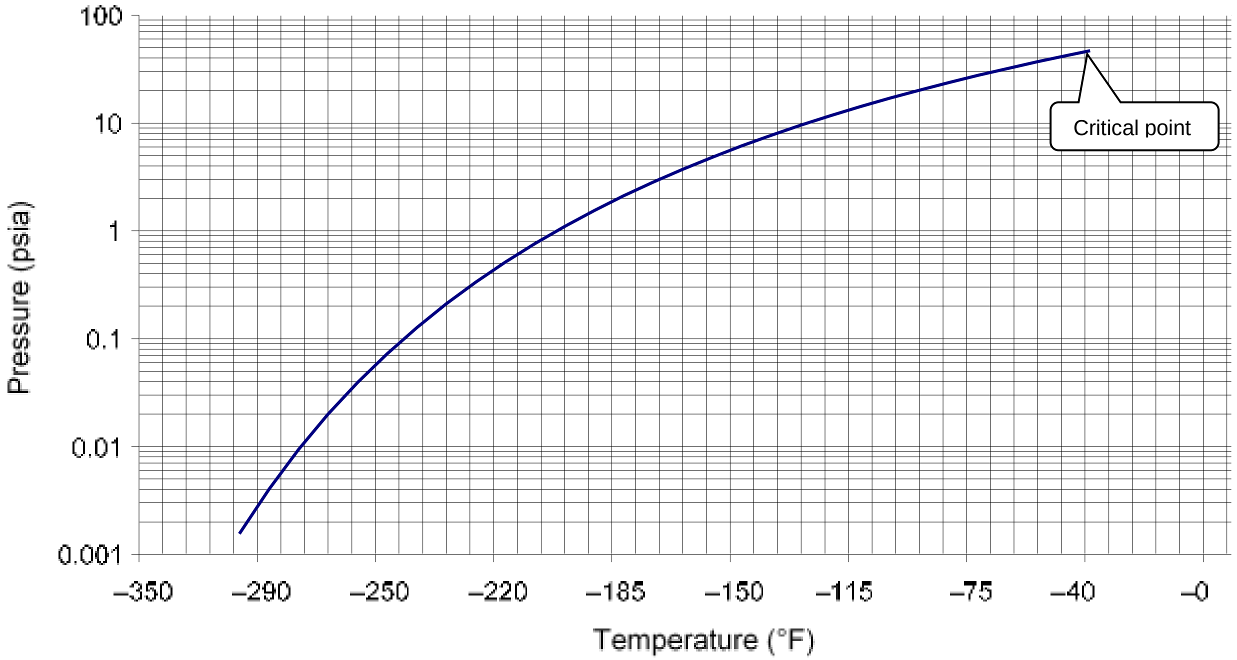

Figure 2—Vapour pressure curve (US Units)

5 Oxidizing and reactivity hazards

5.1 Introduction to fire and explosion hazards

Several flash fires have occurred in equipment containing nitrogen trifluoride at elevated pressure. In many cases, an elastomeric material burnt, for example, valve seat, sealing washer. In some cases, the metallic parts also ignited. Due to the elevated nitrogen trifluoride pressure, the burning materials were projected in the surrounding area.

Figure 3 illustrates that combustion requires the simultaneous occurrence of the following elements:

- presence of an oxidizer (nitrogen trifluoride);
- combustible material in contact with the oxidizer; and
- source of ignition energy.

For each of these elements, several factors influencing the combustion shall be considered. See 5.2, 5.3, and 5.4.

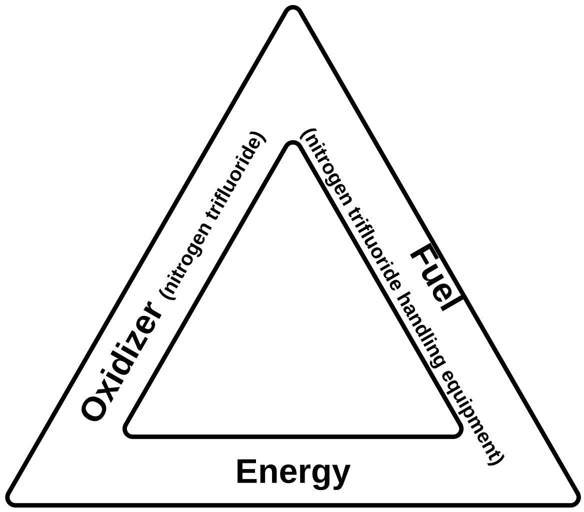

Figure 3—Fire triangle

5.2 Factors influencing combustion—Nitrogen trifluoride considerations

The following factors influence the combustion of materials.

5.2.1 Nitrogen trifluoride pressure

Nitrogen trifluoride is relatively inert at atmospheric pressure and ambient temperature. The auto-ignition temperature of some combustible materials in nitrogen trifluoride can decrease with increasing nitrogen trifluoride pressure, making the material more susceptible to ignition. Likewise, operating at high pressures increases the chance for adiabatic compression (see 5.4.2) to generate high temperature (see 5.2.2).

5.2.2 Nitrogen trifluoride decomposition temperature

The primary concern with nitrogen trifluoride at higher temperatures is the dissociation of nitrogen trifluoride into reactive fluorine species that can react with most materials. These reactive species can lead to uncontrolled reactions with elastomers or certain metals, that liberates heat causing further dissociation of nitrogen trifluoride. Therefore, precautions shall be taken to prevent conditions or mechanisms that could lead to inadvertent heating of nitrogen trifluoride.

The auto-ignition temperature of a material in contact with nitrogen trifluoride is more easily reached as the temperature of nitrogen trifluoride increases. Nitrogen trifluoride systems should operate at as low a temperature as is practicable.

5.2.3 Nitrogen trifluoride velocity in pipelines

Nitrogen trifluoride velocity will create heat by particle impacts, see 5.4.1, on the material, particularly in areas with tortuous passages and/or small crevices. This creation of heat can initiate a local combustion if the auto-ignition temperature of the material in contact with nitrogen trifluoride is reached. Therefore, nitrogen trifluoride velocity shall be limited to avoid the risk of this temperature being achieved. The risk of a particle and the resulting energy imparted by the high velocity in an oxidizing environment can lead to an ignition. This highlights the need to clean nitrogen trifluoride systems for oxidizing service.

The oxipotential of nitrogen trifluoride is greater than that of oxygen (1.6, where oxygen = 1) [6]. However, in the absence of other data, the following velocity limits should be applied, see EIGA Doc 13 for velocity limits in oxygen [3]:

- For pressures greater than 15 bar, the maximum nitrogen trifluoride velocity in pipelines shall be limited so that the product of velocity and pressure does not exceed 450 bar m/s:

  PV less than or equal to 450 bar m/s

  Where:

  V = nitrogen trifluoride velocity in pipelines (m/s)

  P = pressure in the pipeline (bar)

- For pressures less than 15 bar, the maximum velocity in pipelines is less of a concern; however, it is recommended that every effort be made to control this to less than 30 m/s.

For equipment other than pipelines, recommendations are contained in Section 7.

5.3 Factors influencing combustion—Material considerations

The most oxidant compatible materials should be used with nitrogen trifluoride. In all cases, the materials shall be thoroughly cleaned and free from oils, grease, dirt and particles. Even compatible lubricants shall be used sparingly.

When in contact with nitrogen trifluoride, materials of concern include:

- parts of the nitrogen trifluoride handling equipment such as some metals, elastomers, lubricants; and
- contamination present in the equipment such as particles, swarf, dirt, grease and insects

Factors influencing the combustion of these materials are as follows.

5.3.1 Auto-ignition temperature of materials

The auto-ignition temperature is an important factor that needs to be considered when choosing materials to resist combustion in nitrogen trifluoride. The risk of combustion is greater than when the auto-ignition temperature is low since the energy required to reach this temperature is lower.

Methods to determine the auto-ignition temperatures of materials in oxygen, as those described in ISO 11114-3 *Transportable gas cylinders—Compatibility of cylinder and valve materials with gas contents—Part 3: Autogeneous ignition test in oxygen atmosphere*, can also be used for nitrogen trifluoride [15].

5.3.1.1 Metals

The auto-ignition temperatures of three metals in nitrogen trifluoride at 1 bar and 7 bar are given in 4.2. In the incidents mentioned in Section 5, the accidental combustion of a metal is initiated by the combustion of another material having a lower auto-ignition temperature than the metal such as elastomers, lubricants, or contaminants in the nitrogen trifluoride handling equipment (more commonly known as the kindling effect).

5.3.1.2 Non-metals

Auto-ignition tests of elastomers and lubricants have been conducted with nitrogen trifluoride at 70 bar (1000 psi). Highly fluorinated elastomers such as polytetrafluoroethylene (PTFE), including glass and bronze-filled types, Kalrez®, and polychlorotrifluoroethylene (PCTFE) are common elastomeric materials used for nitrogen trifluoride applications and exhibit a high resistance to ignition at high temperatures (> 400 °C [750 °F]). Less fluorinated elastomers demonstrate a tendency to auto-ignite in nitrogen trifluoride at temperatures less than 400 °C (750 °F) with some as low as 240 °C (460 °F) [16].

Halocarbon or perfluorinated lubricants are used for nitrogen trifluoride service and exhibit a similar high resistance to ignition at temperatures greater than 400 °C (750 °F). Some halocarbon greases can dissolve in nitrogen trifluoride [16].

5.3.2 Self-propagation of ignition of metals

The self-propagation of metals ignited in nitrogen trifluoride is also an important factor that needs to be considered when selecting metal equipment components. In particular, when metals are in contact with materials having a lower auto-ignition temperature such as elastomers. The consequences of the auto-ignition of sensitive materials (for example, polymers or non-metals) are aggravated when a metal selfpropagates from ignition under nitrogen trifluoride pressure. The degree of self-propagation is a function of the nitrogen trifluoride pressure and material.

Recent promoted combustion tests of metal rods have shown Monel® 400, Nickel 200, and aluminium to exhibit the lowest potential to self-propagate at pressures greater of 70 bar (1000 psi). Hastelloy® C276 and Hastelloy® C22 have demonstrated self-propagation at pressures between 5 bar and 50 bar, while most of the stainless and carbon steels can self-propagate at pressures less than 5 bar. However, the value of threshold pressures alone cannot be used to determine a metal's resistance to propagation since there are several other combustion properties that can impact the selection of a metal for specific nitrogen trifluoride service conditions [16].

NOTE Although aluminium has a relatively high nitrogen trifluoride threshold pressure, it is not recommended due to its high specific heat of combustion (see 5.3.5) and low melting point (see 5.3.4).

Critical metal components that are in contact with elastomeric parts of or used in severe nitrogen trifluoride conditions should be selected in order to minimize self-propagation from ignition under nitrogen trifluoride pressure. When it is impractical to select the best metal materials, a risk assessment shall be undertaken to determine if any preventive measures are required, for example, fire resistant barrier with remote access to isolate personnel or the use of fire resistant PPE.

5.3.3 Specific heat of materials

Metals have a significantly higher specific heat than non-metals and therefore absorb significantly more heat with a lower temperature increase. Hence, metals are the preferred materials for use with nitrogen trifluoride.

5.3.4 Thermal conductivity of materials

The higher the thermal conductivity of a material, the greater the rate of heat dissipation, and the lower the temperature can be at any point of localised heating.

As metals have a higher thermal conductivity than non-metals, metals are the preferred materials.

Copper and its alloys such as brass, nickel, and Monel® have a better thermal conductivity than stainless steel and therefore may be preferred for critical components such as valve seat supports and filters.

NOTE There could be other considerations such as chemical reactivity, heat of combustion, etc. For example, aluminium and its alloys, which have good thermal conductivity, are not recommended for other reasons (see 5.3.5).

5.3.5 Heat of combustion of materials

This is the energy produced by the combustion of a material in contact with nitrogen trifluoride. If combustion of an elastomer or contaminant within the nitrogen trifluoride handling equipment should occur, the heat produced can be sufficient to initiate the combustion of other materials such as metals.

Therefore, materials with a low specific heat of combustion should be chosen wherever practicable.

Fluorocarbon elastomers such as PTFE and PCTFE produce less energy than hydrocarbon elastomers and consequently are preferred.

Aluminium and its alloys have a very high specific heat of combustion and a lower melting point than some other metals. Therefore, they are not recommended for use within nitrogen trifluoride handling systems especially small components.

5.3.6 Size and configuration of equipment

For a given mass of material, the risk of ignition increases with the surface area exposed to nitrogen trifluoride. Therefore, very careful material selection is necessary for equipment components with a low mass and a high surface area that can be exposed to an ignition in contact with nitrogen trifluoride, for example, filters. Contaminants such as swarf also have a high surface area to mass ratio and shall be excluded.

With regard to shape, rapid changes in direction of flow, such as sharp bends in pipes or obstacles in the flow path, can result in a localised energy increase due to impingement of flowing particles on the surface. These factors should be taken into account when designing nitrogen trifluoride handling equipment.

5.3.7 Quantity of material

The most combustible materials generally have a high specific heat of combustion (for example, non-metallic materials such as elastomers), which can initiate the combustion of other materials.

Where non-metallic materials are used, their mass shall be kept to the minimum practicable and they should be in close contact with a metal support. The metal support should contain sufficient material to dissipate any heat that can be generated by the combustion of the non-metallic material.

5.3.8 Cleanliness of equipment

Contaminants within the handling equipment can ignite in contact with nitrogen trifluoride (for example, particles, swarf, dirt, grease). Such contaminants shall be removed before the introduction of nitrogen trifluoride. Cleaning is described more extensively in 6.4.

5.4 Other factors influencing combustion—energy source

5.4.1 Particle impacts

Solid particles travelling at high velocity in a nitrogen trifluoride gas stream can initiate the ignition of sensitive materials on impact, for example, elastomers.

5.4.2 Adiabatic compression

A sudden increase in the pressure of nitrogen trifluoride or rapid operation of certain flow control equipment can result in a rapid temperature increase. At very high rates of temperature increase, there can be insufficient time for heat exchange to take place with the materials in contact with the hot nitrogen trifluoride. Such a high temperature could be sufficient to cause the nitrogen trifluoride to decompose into more reactive species or initiate the auto-ignition of a non-metallic material.

For example, adiabatic compression can occur when a valve is opened and a system is rapidly pressurised with nitrogen trifluoride. Reducing the rate at which such a valve is opened, so as to reduce the rate of pressure increase in the system, can reduce the risk of an ignition.

Using equipment designed to resist the effects of adiabatic compression is also a way to limit the risk of ignition.

5.4.3 Mechanical friction of equipment moving parts

Localised hot spots can occur from the inadvertent rubbing of two materials, for example, defective or incorrectly specified equipment. Mechanical equipment shall be carefully selected and maintained to avoid this risk.

6 Nitrogen trifluoride handling equipment—general considerations

6.1 Design principles

The equipment used to handle nitrogen trifluoride shall be designed, constructed, and tested in accordance with the regulatory requirements of the country in which the equipment is operated. The equipment shall be designed to withstand the maximum pressure and temperature at which it is to be operated.

A hazard and operability study (HAZOP*)* shall be carried out on all nitrogen trifluoride systems.

As nitrogen trifluoride is an oxidizer, consideration shall be given to the following issues when designing systems to handle nitrogen trifluoride:

- materials of construction and compatibility of lubricants and sealing compounds;
- minimisation of the effects of adiabatic compression;
- gas velocities;
- initial cleanliness and passivation;
- valve types;

- filter materials;
- operating procedures;
- maintenance procedures;
- separation of nitrogen trifluoride from flammable gases (see also 6.9);
- heat dissipation; and
- compression.

6.2 Materials of construction

If a material that is not listed in 5.3.1 is required to be used in nitrogen trifluoride service and is not referenced as compatible in ISO 11114-1, *Gas cylinders—Compatibility of cylinder and valve materials with gas contents—Part 1: Metallic materials*, it should be tested to confirm its suitability for use under defined temperature pressure and flow conditions [17].

Consideration shall also be given to the compatibility of lubricants, seals, and sealing compounds that can come into contact with nitrogen trifluoride under normal or failure conditions, see 5.3.1.2.

6.3 Gas velocities

The velocity of nitrogen trifluoride in pipelines shall be in accordance with 5.2.3. For equipment other than pipelines, for example, for high pressure cylinder valves, specific design shall consider guidance in Section 5 and 7.2.2.

6.4 Cleaning and passivation after installation and maintenance

To ensure that the surfaces that come into contact with nitrogen trifluoride are free from combustible materials and metallic particles that could be introduced into the system during its construction, fabrication, or after maintenance, all equipment shall be:

- cleaned for oxygen use (using detergents or cleaning agents that are free from fine particles and metal chips) [18, 19]; and
- dried, using a dry, oil-free inert gas.

In addition, systems handling high pressure nitrogen trifluoride (pressures greater than 10 bar) can undergo passivation. The purpose of passivation is to ensure that any active sites on the surface of gas wetted parts of a system are fully oxidised under controlled conditions before introducing the pure process gas. Typically, the passivation process requires the introduction of a dilute fluorine/inert gas mixture into the high-pressure nitrogen trifluoride system in steps of increasing pressure (for example, 10 bar) and holding the pressure for 15 min at each stage until the maximum working pressure is reached. At the first passivation, the concentration of fluorine in the mix is normally in the range of 1% to 3%. The use of this low concentration prevents a rapid temperature rise. If the temperature becomes greater than 40 °C (104 °F), the fluorine mixture should be purged out of the system with an inert gas. During passivation, the moving parts of the system such as valves, pressure reducers, and pumps, should be operated for some time to ensure that each active surface is passivated (for example, open-close-open for valves and pressure reducers and run-stop-run for pumps).

6.5 Valves

Ball valves are not recommended for general use in nitrogen trifluoride service due to the potential for adiabatic compression in closed downstream systems occurring as a result of the rapid opening of this type of valve. The use of ball valves should be restricted to isolation functions only and limited to pressures less than 7 bar.

Where possible, valves are selected so the velocity through the valves, when fully open, is no greater than the design velocity of the system. The design should be so the valves can be opened and closed slowly, for example, ball valves shall not be used.

Valves that could be subjected to rapid pressure rise should contain the minimum practicable quantity of elastomers.

For cylinder valves, see 7.2.2.

6.6 Filters

Care shall be taken when selecting filters for use in nitrogen trifluoride service due to its high oxidising potential. Filters made from materials that have a high auto-ignition temperature and a high thermal conductivity should be used. Sintered metal filters made from nickel are recommended. Mesh filters and filters made from stainless steel are not recommended, as they are more likely to ignite in nitrogen trifluoride.

6.7 Operating procedures and personnel

As with any operation associated with a hazardous material, written operating procedures and a competency assessment shall be prepared to ensure that operators understand that the equipment shall be operated within its design parameters, so as not to cause a hazard to personnel or damage to the equipment or environment.

Consideration shall also be given to the use of PPE when handling nitrogen trifluoride and to minimizing personnel exposure when nitrogen trifluoride is being processed under high pressure (for example, by using remote operation).

6.8 Maintenance procedures

A procedure shall be written to cover maintenance activities. Particular consideration shall be given to ensuring that the cleanliness of the system is maintained and that replacement parts and lubricants are compatible with nitrogen trifluoride. The need for passivation of equipment after any maintenance operation (before reintroduction of nitrogen trifluoride) shall be assessed.

6.9 Separation from incompatible gases

To ensure that there is no risk of inadvertent mixing of nitrogen trifluoride with incompatible gases or materials:

- Nitrogen trifluoride handling equipment shall be dedicated to nitrogen trifluoride service and shall not be used for any other purpose; and
- Where it is necessary to use a purge gas (for example, nitrogen), precautions shall be taken to ensure the purge gas cannot be contaminated with incompatible materials (for example, from another process) or with nitrogen trifluoride.

6.10 Compression

During compression two main factors create heat:

- adiabatic compression; and
- mechanical moving part friction.

Heat dissipation and compression ratio are therefore particularly important considerations when compressing nitrogen trifluoride.

7 Nitrogen trifluoride cylinder filling

7.1 Filling facility considerations

Local fire and other applicable regulations shall be met.

Cylinders, cylinder bundles, tubes, ISO modules, and filling systems containing nitrogen trifluoride shall be protected against fire risk. This can be achieved by locating the containers at least 5 m away from flammable materials or by separating the containers using fire resistant walls.

Storage containers shall be located in well ventilated areas where the temperature of the container cannot exceed the maximum set by local regulations.

Filling operations should be located inside rooms with adequate ventilation, for example, at least 6 air changes per hour or under outside shelters with natural ventilation.

Nitrogen trifluoride detectors shall be placed in areas such as ventilation exhausts, near critical high pressure nitrogen trifluoride equipment, for example, compressor, filling areas, to detect a leak as soon as possible. If a nitrogen trifluoride leak is detected, the nitrogen trifluoride sources valves should close automatically. This should include both the nitrogen trifluoride supply and the nitrogen trifluoride cylinders being filled.

Depending on materials selected, preventive measures shall be taken to protect operators, for example, fire resistance barrier with remote access or operator wearing gloves and eye protection. Remote operation of high pressure systems shall be undertaken, wherever feasible

Personnel who operate nitrogen trifluoride systems shall have a good understanding of the properties and hazards of nitrogen trifluoride, see Section 5. They should also be trained to take action in the event of an emergency, see Section 10.

Materials that are to be used in nitrogen trifluoride service shall be kept clean (free from oil, particles, etc.) and stored in a clean environment. Care shall be taken when changing gas wetted components (for example, cylinder valve outlet gasket washers) to avoid contamination from oil that can be on the operator’s hands. Consideration should be given to wearing suitable gloves for such operations.

7.2 Nitrogen trifluoride containers and associated equipment

7.2.1 Containers

In accordance with regulatory requirements as defined by the authority having jurisdiction (AHJ), materials of construction for containers used in nitrogen trifluoride service are carbon steel, nickel, and stainless steel. See also ISO 11114-1 [17]. The internal cleanliness of the containers is important. Additional cleaning can be undertaken to remove trace contaminants.

Where it is necessary to change the service of containers from a different product service into nitrogen trifluoride, cleaning shall be undertaken to ensure it is safe to introduce nitrogen trifluoride. This cleaning shall include the removal of any materials likely to react with nitrogen trifluoride and may include solvent washing, internal shot blasting, vacuum baking, etc.

Where bundles and tube modules are used for transporting and storing nitrogen trifluoride, the individual cylinders or tubes in the bundle and module respectively are usually manifolded together, and terminate with one connection point. It is recommended that isolation valves are fitted on each individual receptacle to reduce the amount of product that could be lost in the event of a leak on the downstream equipment. Bundles and modules are normally fitted with manifold isolation valves to enable the complete gas containment package to be isolated during transport. For nitrogen trifluoride service, each cylinder shall be fitted with an individual shutoff valve. The frame system is allowed to be on skids or wheels to permit movement.

In the event of a leak, it can be difficult to approach or get access to the bundle or module to enable isolation of the source of nitrogen trifluoride. It is recommended that a master actuated outlet valve be installed on or connected to the bundle or module manifold. This valve could be closed remotely by manual intervention or by a signal from a gas or fire detector in the event of an incident. Wherever practicable, this valve should be used exclusively for emergency shutdown of the system.

7.2.2 Cylinder valves

Cylinder valves for nitrogen trifluoride service shall be designed taking into account the requirements contained in Section 5. While stainless steel is normally used to house a PTCFE seat in the valve stem, consideration shall be given to the use of elastomers with an auto-ignition temperature greater than 475 °C (887 °F) in a nickel housing (see 5.3.1.1 and 5.3.1.2).

Due to the nitrogen trifluoride velocity inside valves that are fitted to cylinders and tubes, the valves shall be designed to withstand the service conditions and shall be constructed of materials and lubricants that are compatible with nitrogen trifluoride (see Section 6).

Cylinder valve types should be tested before being used for nitrogen trifluoride service. Such tests can include adiabatic testing with oxygen and endurance testing [20]. Suitably designed pneumatically actuated valves have been found to be satisfactory in nitrogen trifluoride service, although these valves shall be designed to open slowly to avoid adiabatic compression.

7.2.3 Cylinder filling ratios

Nitrogen trifluoride cylinders are normally filled by weight because pressure measurement cannot be readily relied upon to determine cylinder content over a range of temperatures.

The recommended filling ratio is 0.5 kg/l, which equates to a filling pressure of approximately 100 bar at 20 °C. See Figure 4.

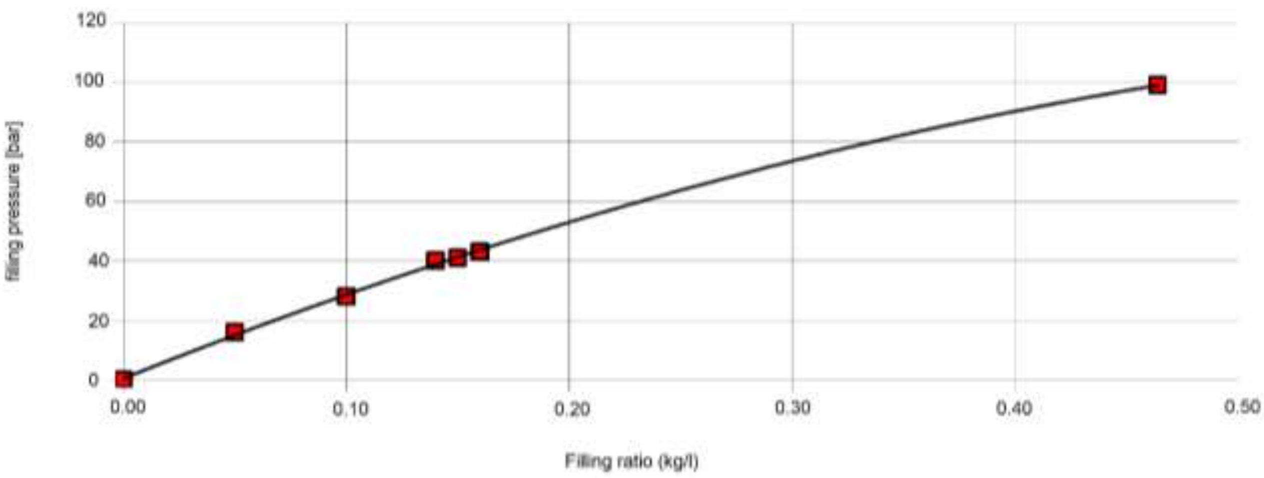

Figure 4—Filling pressure versus filling ratio (at 20 °C)

7.3 Cylinder filling equipment

7.3.1 Filling manifold

Pipeline components in contact with nitrogen trifluoride filling shall be designed in accordance with 5.2.3 and 6.3. Cylinder valves and other equipment creating a higher velocity due to pressure drop shall be designed and constructed according to the requirements contained in Section 5. Particular attention shall be paid to filters and valve seat materials.

When not under nitrogen trifluoride pressure, manifolds should be under constant inert gas flow through purge, vented to a safe location and/or plugged to ensure that any contaminants are excluded.

The design of filling manifold pigtails should ensure that nitrogen trifluoride velocities are in accordance with 5.2.3. Under certain conditions, for example, a full cylinder being vented, it may not be possible to comply with 5.2.3; however, such operations could be safely achieved by operating valves remotely and ensuring the system is clean. Convoluted stainless steel flexible hoses or small diameter (flexible) or stainless steel tube can also be used.

7.3.2 Compressors

Consideration should be given to the location of a nitrogen trifluoride compressor in a separate enclosure provided with remote start-up and shutdown capability.

Nitrogen trifluoride compressors shall be specifically designed for nitrogen trifluoride service. Nitrogen trifluoride hot wetted parts (for example, valves) should be made of nickel or Monel®.

Where it is absolutely necessary to use non-metallic components, for example, washers and seats, only PTFE or PCTFE shall be used.

Consider the use of perfluorinated lubricants, which are more compatible with nitrogen trifluoride, as these lubricants could be exposed to nitrogen trifluoride in the event of equipment failure.

The heat generated by the compression of nitrogen trifluoride shall be considered and the compressor design shall minimise the nitrogen trifluoride gas temperature, see 5.2.2. This can be achieved by:

- Limiting the compression ratio and undertaking the required compression in several stages, possibly cooling the gas between each stage, if necessary;
- Choosing materials with high thermal conductivity for components that are in contact with the gas;
- Limiting the rate at which the gas is compressed. This can be particularly important where high compression ratios are used, for example, single stage piston compressors; or
- Introducing a high temperature interlock to shut down the system in the event of excessive temperatures.

7.3.3 Vacuum pumps

Vacuum pumps in contact with nitrogen trifluoride shall be either dry pumps or an oil sealed pump using a perfluorinated fluid.

7.3.4 Pressure gauges

Before use and installation, care shall be taken to ensure that pressure gauges are cleaned internally to a standard equivalent to that used in oxygen service. Care shall be taken to ensure that cleaning materials are also removed, for example, solvents.

Consideration should be given to the protection of the operator in the event of a pressure gauge failure.

8 Supply to point-of-use

8.1 Facility considerations

Areas where nitrogen trifluoride supply containers are stored and used shall be in accordance with local regulations. In the absence of local regulations, a well-ventilated area 5 m away from any fire risk or separated by a fire resistant barrier is recommended.

Consideration shall be given to firefighting and the arrangements to keep supply gas containers cooled in the event of a fire.

Materials that are to be used in nitrogen trifluoride service shall be kept clean (free from oil, particles, etc.) and stored in a clean environment. Care shall be taken when changing gas wetted components (for example, cylinder valve outlet gasket washers) to avoid contamination from oil that can be on the operator’s hands. Consideration should be given to wearing compatible gloves such as nitrile for such operations.

8.2 Gas supply manifolds

Gas supply manifolds shall be located in a well-ventilated area. When located indoors, adequate ventilation should be provided (at least 6 air changes per hour). Gas cabinets are often used for this purpose.

Provisions shall be made to deal with emergencies such as leaks and reactions within nitrogen trifluoride supply systems, see Section 10.

Prior to introducing nitrogen trifluoride for the first time, all parts of the gas supply system that are likely to come into contact with nitrogen trifluoride at pressures greater than 10 bar should be cleaned and passivated, see 6.4.

Precautions shall be taken to ensure that nitrogen trifluoride does not inadvertently come into contact with any flammable gas or other non-compatible material. Non-return valves shall not be relied upon alone to provide protection from contaminating the nitrogen trifluoride supply due to backflow of other gases in the system.

A purge gas is often used to purge parts of the nitrogen trifluoride system after supply cylinder change over or maintenance work. Precautions shall be taken to ensure that the purge gas supply does not become contaminated with nitrogen trifluoride. It is recommended that a dedicated purge gas source, for example, a cylinder supply, is used that will eliminate the risk of backfeeding (via the purge gas system) into another process gas supply system.

8.3 Operating procedures and personnel

All operations involving nitrogen trifluoride shall be covered by written operating procedures.

A risk assessment should be carried out on all operations involving nitrogen trifluoride.

Components and materials that can be used on nitrogen trifluoride supply systems, for example, during cylinder change over or equipment maintenance, shall be clearly identified, carefully stored, and handled to ensure that they do not become contaminated. It is recommended that cylinder valve outlet connection gaskets are only handled while wearing approved gloves. This will avoid the risk of contamination of the gasket by the natural oils found on the skin.

All personnel involved in the handling of nitrogen trifluoride and the operation of nitrogen trifluoride supply systems shall be trained. This training shall include the importance of cleanliness and the need for exclusive use of specified materials and components on nitrogen trifluoride gas handling systems.

Personnel who operate gas supply manifolds or change-over supply cylinders shall have an understanding of the properties and fire and explosion hazards of nitrogen trifluoride, see Section 5. They should also be trained to take action in the event of an emergency, see Section 10

When it is impracticable to select the best materials according to 5.3.1 and 5.3.2, preventive measures shall be considered to protect operators, for example, fire resistant barrier, gas cabinet with remote access, or operator wearing gloves and eye protection. Remote operation of high pressure systems should be undertaken, wherever practicable.

9 Gas abatement systems—Basic principles of abatement

Where possible, it is recommended that nitrogen trifluoride is recycled or recovered. Nitrogen trifluoride can be disposed of by a variety methods including:

- $2NF_3 + 2AlCl_3 \longrightarrow N_2 + 3Cl_2 + 2AlF_3$ at 70 °C
- $2NF_3 + 3H_2 \longrightarrow N_2 + 6HF$ (very intensive reaction)
- $2NF_3 + 2Fe \longrightarrow 2FeF_3 + N_2$ at 300 to 400 °C
- $4NF_3 + 3Si \longrightarrow 3SiF_4 + 2N_2$ at greater than 400 °C
- thermal ionisation with reactants;
- plasma ionisation with reactants; and

- in combination with perfluorocarbon (PFC) recovery systems

For more information on disposal of gases, see EIGA Doc 30 [1].

After use in a process, for example, in an exhaust system, contamination could be present and a chemical abatement system could be necessary. Such an abatement system could also deal with other PFCs that could be present in the system. There are a number of small scale solid state abatement systems commercially available.

10 Emergency response

It is always important to be prepared for an emergency situation and the following information should be used as a guide for what actions to take in the event of an emergency and what information should be included in an emergency procedure. Special training is necessary for emergency response. See AIGA 004 and CGA's *Handbook of Compressed Gases* [2, 21].

In the event of a leak involving nitrogen trifluoride isolate all the sources of nitrogen trifluoride where possible by closing the valves on the cylinder, bundle, tube module, and any cylinders that could be in the process of being filled.

To help control small fires, use carbon dioxide or water extinguishers. Carbon dioxide might not extinguish a reaction but it could help to cool down the area and limit the reaction. Do not use Halons, dry ammonium phosphate, or bicarbonate on nitrogen trifluoride fires as they produce toxic by-products. Water can be used for fires covering a large area.

Before attempting to tackle any emergency situation, always ensure that personnel are trained and PPE is worn.

11 References

[1] AIGA 083, *Disposal of Gases*, www.asiaiga.org

NOTE This publication is part of an international harmonization program for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonized regional references.

[2] AIGA 004, *Handling gas container emergencies*, www.asiaiga.org

[3] AIGA 021, *Oxygen Pipeline and Piping Systems,* www.asiaiga.org

NOTE This publication is part of an international harmonization program for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonized regional references.

[4] *Recommendations on the Transport of Dangerous Goods, Model Regulations,* United Nations Economic Commission for Europe, www.unece.org

[5] *Globally Harmonized System of Classification and Labelling of Chemicals (GHS)*, United Nations Economic Commission for Europe www.unece.org

[6] ASTM STP 1395, *Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres*, ASTM International, 100 Barr Harbor Dr., West Conshohocken, PA 19428. www.astm.org

[7] Regulation (EC) No. 1272/2008, *Classification, Labelling and Packaging of Substances and Mixtures*. European Commission, www.ec.europa.eu

[8] CGA C-7, *Guide to the Classification and Labeling of Compressed Gases,* Compressed Gas Association, Inc., www.cganet.com

[9] *Nitrogen Trifluoride*, Occupational Safety and Health Administration (OSHA) at website www.osha.gov/dts/chemicalsampling/data/CH_257500.html

[10] *NIOSH Pocket Guide to Chemical Hazards*, National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention, 1600 Clifton Rd., Atlanta, GA 30333. www.cdc.gov/niosh

[11] Gas supplier's safety data sheet.

[12] Vernot, E.H., Haun, C.C., MacEwen, J.D., and Egan, G.F., "Acute Inhalation Toxicology and Proposed Emergency Exposure Limits of Nitrogen Trifluoride", J*ournal of Toxicology and Applied Pharmacology*, September 1973, Volume 26, Issue 1, 1-13. www.sciencedirect.com

[13] Dinman, BD. "Recommendation for Revised Emergency Exposure Limits for Spills of NF_3," J*ournal of Toxicology and Applied Pharmacology*, June 1974, Volume 28, Issue 3, 498-499. www.sciencedirect.com

[14] *Nitrogen trifluoride results*, Acute Exposure Guideline Levels (AEGLs), U.S. Environmental Protection Agency at website www.epa.gov/aegl/nitrogen-trifluoride-results-aegl-program

[15] ISO 11114-3, *Transportable gas cylinders—Compatibility of cylinder and valve materials with gas contents—Part 3: Autogeneous ignition test in oxygen atmosphere*, www.iso.org

[16] Newton, B.E., and Chiffoleau, G. "Materials Compatibility with Nitrogen Trifluoride (NF_3)", *Journal of ASTM International*, May 2006, Volume 3, Issue 5, 1-16. ASTM International, 100 Barr Harbor Dr., West Conshohocken, PA 19428. www.astm.org

[17] ISO 11114-1, *Gas cylinders—Compatibility of cylinder and valve materials with gas contents—Part 1: Metallic materials*, www.iso.org

[18] AIGA 012, *Cleaning of equipment for oxygen service,* www.asiaiga.org

[19] CGA G-4.1, *Cleaning Equipment for Oxygen Service*, Compressed Gas Association, Inc., www.cganet.com

[20] ISO 10297, *Gas cylinders—Cylinder valves—Specification and type testing*, www.iso.org

[21] *Handbook of Compressed Gases*, 5th edition, Compressed Gas Association, Inc., www.cganet.com

Appendix A—Audit checklist

It is recommended that facilities handling nitrogen trifluoride undergo periodic audits to assess their compliance with this publication and with other recognised safe working practices. The nature and detail of such audits are determined by the type of work undertaken at the facility, the level of involvement with nitrogen trifluoride, and compliance with local regulations.

The checklist given in the following pages is not exhaustive for all nitrogen trifluoride facility audit applications; however, it provides a helpful starting point. There are separate checklist sections that address nitrogen trifluoride cylinder filling and nitrogen trifluoride supply systems; however, the other checklist sections could be applicable to all nitrogen trifluoride handling facilities. The “Ref” column gives, the section of this publication where more information on the checklist item can be found.

No	CHECKLIST ITEM	Ref
1	**Nitrogen trifluoride storage area**	
1.1	Are nitrogen trifluoride cylinders and other containers stored in a well-ventilated area, at least 5 m away from flammable materials or separated by a fire-resistant wall?	7.1, 8.1
1.2	Does the nitrogen trifluoride storage facility meet local fire regulations (where applicable)?	7.1, 8.1
1.3	Is the storage area labelled?	—
1.4	Are cylinders in the storage area secured to prevent them falling over and are their valve protection caps fitted?	—
2	**Nitrogen trifluoride filling procedures and equipment**	
2.1	Has the nitrogen trifluoride filling equipment been designed by engineers who are familiar with the properties of nitrogen trifluoride and the precautionary measures and material requirements necessary for its safe handling (as set out in this publication)?	ALL
2.2	Has a HAZOP been carried out on the system?	6.1
2.3	Has a risk assessment been performed?	8.3
2.4	If there is any uncertainty with respect to items 2.1, 2.2, or 2.3, detailed and documented reviews of the process equipment drawings, system design, and all component specifications should be carried out to confirm compliance with this publication.	ALL
2.5	Is the nitrogen trifluoride cylinder filling system and all its component parts located in well ventilated areas away from fire risk?	7.1
2.6	Are there written operating procedures for nitrogen trifluoride cylinder filling equipment? Do these procedures take into account all the recommended operational precautions set out in this publication?	6.7, 7
2.7	Is the nitrogen trifluoride cylinder filling equipment dedicated to nitrogen trifluoride service?	6.9
2.8	Are all flammable gases separated from the nitrogen trifluoride cylinder filling equipment?	6.9
2.9	Is there a nitrogen trifluoride compressor? Does it comply with the recommendations in this publication?	7.3.2
2.10	Is there a purge gas associated with the nitrogen trifluoride cylinder filling equipment? If so, is it a dedicated supply? If it is not a dedicated supply (for example, house	6.9

2	**Nitrogen trifluoride filling procedures and equipment**	
	supply), are precautions taken to ensure that the purge gas is not contaminated with flammable materials or cannot become contaminated with nitrogen trifluoride?	
2.11	Are all lubricants that could come into contact with nitrogen trifluoride compatible with nitrogen trifluoride (for example, vacuum pump and compressor oils)?	5.3, 6, 7.2
2.12	Are nitrogen trifluoride cylinders approved for and dedicated to nitrogen trifluoride service? If not, are they prepared prior to filling to ensure they are not contaminated with any materials that can react with nitrogen trifluoride?	7.2.1
2.13	Have the nitrogen trifluoride cylinder valves been approved for nitrogen trifluoride service by a recognized expert within the gas company and/or a competent external authority?	7.2.2
2.14	Are cylinder valves prepared prior to use to ensure they are not contaminated with any materials that can react with nitrogen trifluoride?	7.2.2
2.15	Are only approved compatible gaskets used for sealing valve outlet connections? Do operators take care to ensure that they are in good clean condition before use?	6.2
2.16	Are there checks to ensure nitrogen trifluoride cylinders are not overfilled?	7.3
2.17	Are there checks and controls in place to prevent unauthorised modification of equipment and operating procedures?	—
2.18	Are precautions taken to prevent the contamination of equipment, particularly when it is not in use?	8.2
2.19	Are precautions taken to detect and act upon fire or nitrogen trifluoride leakage (for example, installation of detectors, automatic valve shutoff, etc.)?	7.1
2.20	Has the system been cleaned and inspected prior to operating?	—

3	**Nitrogen trifluoride supply and supply equipment (for cylinder filling or use)**	
3.1	Has the equipment been designed and installed in accordance with this publication?	ALL
3.2	If there is any uncertainty with respect to item 3.1, detailed and documented reviews of the process equipment drawings, system design, and all component specifications should be carried out to confirm compliance with this publication.	ALL
3.3	Are nitrogen trifluoride supply cylinders located in a well-ventilated area away from fire risk?	8.1, 8.2
3.4	Are there written operating procedures for nitrogen trifluoride supply equipment? Do these procedures take into account all the recommended operational precautions set out in this publication?	6.7, 7, 8.3
3.5	Is the nitrogen trifluoride supply equipment dedicated to nitrogen trifluoride service?	6.9
3.6	Are cylinders connected for use secured to prevent them from falling over?	—
3.7	Are all flammable gases separated from nitrogen trifluoride supply equipment?	6.9, 8.2
3.8	Is there a purge gas associated with the nitrogen trifluoride supply equipment? If so, is it a dedicated supply? If it is not a dedicated supply (for example, house supply), are there precautions taken to ensure the purge gas is not contaminated with flammable materials or cannot become contaminated with nitrogen trifluoride?	6.9, 8.2
3.9	Are lubricants that could come into contact with nitrogen trifluoride compatible with nitrogen trifluoride (for example, vacuum pump oil)?	6.8
3.10	Are compatible gaskets used for sealing valve outlet connections and do operators take care to ensure they are in good clean condition before use?	6.2
3.11	Are there checks and controls to prevent unauthorised modification of equipment and operating procedures?	—
3.12	Are precautions taken to prevent the contamination of equipment, particularly when it is not in use?	8.2

4	**Nitrogen trifluoride abatement and abatement equipment**	
4.1	Has a risk assessment been performed to confirm that the arrangements for the disposal of waste nitrogen trifluoride ensure the safety of people and minimise any impact on the environment?	9, 8.1

5	**Maintenance procedures**	
5.1	Are there documented procedures to cover the maintenance of nitrogen trifluoride handling equipment? Are records of work carried out kept?	6.8
5.2	Is nitrogen trifluoride equipment maintenance covered by a permit-to-work procedure, where appropriate?	—
5.3	Are materials and components that can be used during the maintenance of nitrogen trifluoride equipment clearly specified/identified?	—
5.4	After maintenance work, is there a cleaning and purging (plus passivation where appropriate) procedure to be implemented before the equipment is returned to nitrogen trifluoride service?	5.3.7, 6.4

6	**Personnel**	
6.1	Is there a documented training programme on gas handling for all personnel involved in handling nitrogen trifluoride and maintaining nitrogen trifluoride equipment?	—
6.2	Are all personnel involved with nitrogen trifluoride trained to cover their degree of involvement? NOTE It is recommended that representative samples of operational personnel be interviewed during the audit to assess their understanding of the properties of nitrogen trifluoride.	5, 6.7, 7.1, 8.3, 10
6.3	Do personnel who handle nitrogen trifluoride have access to a nitrogen trifluoride SDS?	—
6.4	Do personnel who handle nitrogen trifluoride wear/use PPE?	8.3, 7.1

7	**Emergency response**	
7.1	Is there an emergency response procedure specific to nitrogen trifluoride readily available and are personnel trained in this procedure?	10
7.2	Is there firefighting and PPE readily available in the event of a nitrogen trifluoride ignition and subsequent fire?	10
7.3	Is the local fire department aware of the location of and hazards arising from nitrogen trifluoride on site?	—
7.4	Is there first aid information available on-site?	—