

# **GUIDELINES FOR THE MANAGEMENT OF SF<sub>6</sub> (SULFUR HEXAFLUORIDE) FOR USE IN ELECTRICAL EQUIPMENT**

This document is not a South African National Standard



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## Foreword

This specification was prepared on behalf of the Electricity Suppliers Liaison Committee (ESLC).

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Reference is made in the **NOTE** to **4.6.3.2 (m)** to “the relevant authority”. In South Africa this is the Department of Energy and Trade. Reference is also made in the **NOTE** to **4.6.3.2 (m)** and in **annex F, F.3.2** to “environment conservation legislation”. In South Africa this is the Environment Conservation Act, 1989 (Act No. 73 of 1989) (as amended from time to time).

Reference is made in **4.6.3.3** to “dangerous goods legislation”. In South Africa this is the National Road Traffic Act, 1996 (Act No. 93 of 1996) (as amended from time to time) and the Dangerous Goods Regulations promulgated in terms of the Act.

Reference is made in **table 5, 4.6.3.3, 4.7.1, 4.7.2** and **4.8** to “legislation”. In South Africa this is the said National Road Traffic Act and the regulations promulgated in terms of the Act.

Reference is made in **4.9.1** and in **annex F, F.3.3**, to “national legislation”. In South Africa this is the said National Road Traffic Act, the Hazardous Substances Act, 1973 (Act No. 15 of 1973) (as amended from time to time), the Occupational Health and Safety Act, 1993 (Act No. 85 of 1993) (as amended from time to time) and the National Environmental Management Act, 1998 (Act No. 107 of 1998) (as amended from time to time), and the duty of care principle in terms of the said National Environmental Management Act.

Reference is made in **4.9.3** and in **annex F, F.3.4**, to the “relevant authority”. In South Africa this is the Department of Energy and Trade or the Department of Water Affairs and Forestry (or both).

Annexes F, G and H form an integral part of this document. Annexes A to E and I are for information only.

## **0 Introduction**

### **0.1 General**

Owing to environmental pressures, legislative and other requirements (for example Kyoto Protocol), it is necessary to set out the best practice for the management of SF<sub>6</sub> in terms of its purchase, usage, handling and storage, and the safe disposal of used decomposition by-products and contaminated gas.

This specification was prepared to establish and promote uniform requirements for application in the South African electricity industry.

The Electricity Suppliers Liaison Committee expresses the wish that all supply authorities should adopt the text of this specification insofar as their particular conditions will permit. Any differences between the requirements of this specification and the purchaser's requirements should, as far as possible, be clearly indicated in schedules and, where appropriate, be submitted for consideration in future revisions of this specification.

### **0.2 SF<sub>6</sub> background**

Sulfur hexafluoride (SF<sub>6</sub>) was prepared synthetically in a laboratory for the first time by Moissou and Lebeau in 1900, and is formed by six atoms of fluorine gathered around a centrally situated atom of sulfur. The gas is identified by CAS Number 2551-62-4.

The chemical bond between fluorine and sulfur is known as one of the most stable existing atomic bonds. Six of these grant the molecule very high chemical and thermal stability. In addition, the compatibility of SF<sub>6</sub> with materials used in electric constructions is similar to the compatibility of nitrogen, up to temperatures of about 180 °C.

SF<sub>6</sub> has been produced industrially since 1925, and a patent was granted in 1928 for the use of SF<sub>6</sub> as an arc-quenching medium in circuit-breakers. Since the early 1960s, SF<sub>6</sub> has been successfully used by the electricity industry in power equipment for the HV transmission and MV distribution of electricity (gas-insulated substations, ring main units, circuit-breakers, transformers, cables, etc.). Other non-electrical industrial applications include metallurgy, electronics, scientific equipment, ocular surgery and military applications.

### **0.3 Characteristics of SF<sub>6</sub>**

Pure sulfur hexafluoride is colourless, odourless, non-toxic, and non-flammable. It is an extremely stable gas which is chemically inert and physiologically/biologically not very reactive. It is also one of the heaviest known gases, with a molecular weight of 146,05 g/mol; hence it is five times as dense as air.

The advantages of SF<sub>6</sub> result from its high dielectric strength compared to that of air and its superb quenching property for electric arcs. Compressed SF<sub>6</sub> is therefore extensively used both as a high-voltage insulating medium and as an arc-quenching medium in high-voltage equipment. This includes, but is not limited to, circuit-breakers, gas-insulated substations and transforming devices.

### **0.4 Environmental aspects**

SF<sub>6</sub> has no impact on the stratospheric ozone layer, but is a greenhouse gas that contributes to global warming. SF<sub>6</sub> has a GWP of approximately 22 000 to 29 000 times that of CO<sub>2</sub>. This is because SF<sub>6</sub> is an efficient absorber of infrared radiation, particularly at wavelengths near 10,5 µm. SF<sub>6</sub> has an estimated life of more than 3 000 years in the upper atmosphere, making it the most potent of all known greenhouse gases. Its effect in the atmosphere is therefore accumulative.

The impact on global warming due to the SF<sub>6</sub> concentration in the atmosphere (atmospheric burden) is approximately between 0,01 % and 0,02 % of the overall greenhouse effect, while the annual SF<sub>6</sub> emission rate from the overall electricity industry represents 0,1 % of the annual emission rate of man-made global warming gases.

However, SF<sub>6</sub> does not harm the ecosystem: biological accumulation in the food chain does not occur. It is an inert gas with very low solubility in water so that it presents no danger to surface or ground water or to the soil.

The GWP of SF<sub>6</sub> alone is not adequate to measure the environmental impact of electric power equipment based on SF<sub>6</sub> technology. The environmental impact of any specific application should be evaluated or compared (or both) using the life cycle assessment approach in accordance with the example in ISO 14040.

SF<sub>6</sub> should be used in a closed cycle; i.e. when it is necessary to remove gas from containment, a proper handling procedure should be implemented to avoid any deliberate release into the atmosphere.

Therefore, because SF<sub>6</sub> applied in electric power equipment is inherently contained and not consumed or released, recycling can easily be introduced as a natural part of handling. Users of SF<sub>6</sub> gas should therefore establish a policy to minimize SF<sub>6</sub> losses into the atmosphere by minimizing leakage from equipment and by systematic recycling. Appropriate standards, procedures and equipment should support this policy. See annex A.

In addition, SF<sub>6</sub> should continuously be reused during equipment development, product testing, commissioning, maintenance and repair, and decommissioning. It should also be transferred from equipment being phased out into newly installed equipment. It thus goes through a continual cycle of reuse. Such a systematic reuse of SF<sub>6</sub> requires that the gas be kept at the stated quality level at which it can perform its functions. This can be achieved by proper handling and reclaiming. With properly designed and maintained reclaiming equipment, moisture and reactive by-products can almost always be reduced on site to tolerable impurity levels for reuse. See annex B.

In exceptional cases the gas cannot be purified sufficiently on site, for example owing to excessive contamination with non-reactive gases such as air or CF<sub>4</sub> (or both). In such cases, the on-site purification process allows for the transportation of the non-reusable gas as non-toxic gas, like new SF<sub>6</sub>, for off-site purification in an environmentally compatible way.

The use of SF<sub>6</sub> in electrical equipment will therefore have a negligible impact on the global environment and ecosystem provided that users pay the necessary attention to the containment and management of SF<sub>6</sub>.

## 0.5 Physical properties of SF<sub>6</sub>

Table 1 (from Khalifa, Maller and Naidu – see bibliography) shows the physical properties of SF<sub>6</sub>.

## 0.6 Reactivity data

Sulfur hexafluoride is stable in closed containers at room temperature under normal storage and handling conditions. It does not undergo hazardous polymerization and is non-corrosive. It is a thermodynamically unstable but kinetically stable gas. Sulfur hexafluoride explodes violently on contact with disilane (Si<sub>2</sub>H<sub>6</sub>). It reacts with molten sodium metal at about 250 °C, but is unreactive at 500 °C with steam, or with molten potassium hydroxide. Thermal-oxidative degradation emits highly toxic fumes of fluoride and sulfur dioxide. An electrical discharge causes decomposition of SF<sub>6</sub>, the by-products of which are highly toxic. Corrosive properties are enhanced by moisture, or high temperature. These lower fluorides of sulfur hydrolyse to form hydrofluoric acid and sulfur dioxide.

Table 1 — Physical properties of SF<sub>6</sub>

1	2
Physical properties	Measurement
Molecular weight	146,05 g/mol
Melting point	-50,8 °C
Sublimation temperature	-63,9 °C
Density (liquid at 50 °C)	1,98 g/mL
Density (liquid at 25 °C)	1,329 g/mL
Density (gas at 1 bar and 20 °C)	6,164 g/L
Critical temperature	45,6 °C
Critical pressure	37,53 bar
Critical density	0,755 g/mL
Surface tension (at -50 °C)	11,63 dyn/cm
Thermal conductivity	0,012 W/(m·K)
Viscosity (gas at 25 °C)	1,61E-4 poise
Boiling point	-63,0 °C
Specific heat (at 30 °C)	0,143 cal/g
Relative density (air = 1)	5,10
Vapour pressure (at 20 °C) <sup>a</sup>	21 bar
<sup>a</sup> See annex C for SF <sub>6</sub> vapour pressure curves.	

## 0.7 Health hazards

**0.7.1** Pure sulfur hexafluoride (SF<sub>6</sub>) is non-toxic. It can act as a simple asphyxiant by displacing the amount of oxygen in the air necessary to support life. Inhalation of 80 % SF<sub>6</sub> and 20 % O<sub>2</sub> for five minutes can produce peripheral tingling, a feeling of excitement, and some altered hearing. Inhalation and handling of SF<sub>6</sub> gaseous and solid decomposition by-products on the other hand can lead to serious health complications. The by-products and the hazards associated with the decomposition of these by-products are given in 0.7.2 to 0.7.10 inclusive.

During handling of used SF<sub>6</sub> (maintenance, storage, etc.) extreme caution should be exercised, and the relevant safety, health and environmental procedures should be adhered to.

**0.7.2 Disulfur decafluoride (S<sub>2</sub>F<sub>10</sub>)** is the most toxic but least understood by-product. It is odourless and non-irritating to the respiratory tract. It has a low melting point and is insoluble in water. It can be fatal at levels higher than a mass fraction of 0,025 µg/g (0,025 ppmw) in air.

**0.7.3 Thionyl fluoride (SOF<sub>2</sub>)** is soluble in hot and cold water and reacts to produce toxic corrosive vapours. The gas is irritating to the skin, eyes, mucous membranes and lungs.

**0.7.4 Sulfuryl fluoride (SO<sub>2</sub>F<sub>2</sub>)** is a colourless and odourless gas. It is soluble in cold water and reacts to emit toxic and corrosive vapours. It might act as a narcotic at high concentrations. Oral exposure might cause death or permanent injury.

**0.7.5 Hydrogen fluoride (HF)** is highly corrosive. Contact with it can cause severe burns to the eyes, skin and respiratory tract. It can penetrate the skin, and can thus destroy both deep tissue layers and bone.

**0.7.6 Aluminium trifluoride (AlF<sub>3</sub>)** is a colourless, solid substance. It forms part of the white powder deposit which can be found in electrical apparatus, in particular the breaking chambers of switchgear. It causes irritation of the skin and eyes.

**0.7.7 Hydrogen sulfide (H<sub>2</sub>S)** has an odour that is similar to that of rotten eggs. It can cause eye irritation at relatively low levels, and at high concentrations it can be fatal.

**0.7.8 Carbon tetrafluoride (CF<sub>4</sub>)** is a colourless, odourless and non-flammable gas. It is narcotic and can act as an asphyxiant.

**0.7.9 Sulfur tetrafluoride (SF<sub>4</sub>)** is a colourless gas with an odour similar to that of sulfur dioxide. It is very toxic and deadly at concentrations of over 0,1 µg/g (0,1 ppmw) in air.

**0.7.10 Sulfur dioxide (SO<sub>2</sub>)** is a colourless, non-flammable gas with a strong suffocating odour. The gas is oxidized in water to form sulfurous acid, which can further be oxidized to sulfuric acid. The gas is fatal at concentrations of over 2 µg/g (2 ppmw) in air. It is irritating to the eyes, skin and respiratory tract, mainly because it is an acidic gas.

## 0.8 Origin of contaminants

SF<sub>6</sub> taken from electrical equipment in operation contains several kinds of impurities. Some of them are already present in the new gas, as a result of the manufacturing process. The nature of these impurities and the admissible quantities are reported in IEC 60376 and IEC/TR2 61634.

The expected additional impurities in SF<sub>6</sub> taken from equipment come from both gas handling and the operation, electrical discharges and heating of the equipment. Table 2 summarizes the main impurities and their sources.

**Table 2 — Origin of SF<sub>6</sub> impurities**

1	2	3
SF <sub>6</sub> situation and use	Sources of impurities	Possible impurities
During handling and in service	Leaks, incomplete evacuation and desorption	Air, Oil, H <sub>2</sub> O
Insulating function	Partial discharges: corona and sparking	HF, SO <sub>2</sub> , SOF <sub>2</sub> , SOF <sub>4</sub> , SO <sub>2</sub> F <sub>2</sub> ,
Switching function	Switching arc erosion	H <sub>2</sub> O, HF, SO <sub>2</sub> , SOF <sub>2</sub> , SOF <sub>4</sub> , SO <sub>2</sub> F <sub>2</sub> , CuF <sub>2</sub> , SF <sub>4</sub> , WO <sub>3</sub> , CF <sub>4</sub> , AlF <sub>3</sub>
	Mechanical erosion	Metal dusts, particles
Internal arc	Melting and decomposition of materials	H <sub>2</sub> O, HF, SO <sub>2</sub> , SOF <sub>2</sub> , SOF <sub>4</sub> , SO <sub>2</sub> F <sub>2</sub> , CuF <sub>2</sub> , SF <sub>4</sub> , WO <sub>3</sub> , CF <sub>4</sub> , Metal dusts, particles, AlF <sub>3</sub> , FeF <sub>3</sub>

NOTE Decomposition by-products of SF<sub>6</sub> are not released into the atmosphere in significant quantities. At the end of the service life of an item of equipment they can be converted into naturally occurring neutral products with no adverse impact on the local environment.

## 0.9 Characteristics of electric power equipment

The main applications in electric power equipment utilizing SF<sub>6</sub> are defined by the current IEC standards in force: IEC 62271-200 for MV equipment, IEC 62271-203 for HV equipment, IEC 62271-1 for common specifications, and IEC 62271-100 and IEC 62271-102 for circuit-breakers and disconnectors respectively.

The tightness of certain old installed gas-insulated power equipment, especially for HV systems, could have a significant impact on the environment. Nevertheless, it should be kept in mind that handling SF<sub>6</sub> during installation, on-site testing and maintenance activities might contribute significantly to the overall emissions.

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State-of-the-art electric power equipment is designed and manufactured for tightness so that it is compatible with the environment. This implies:

- a) very low leakage rates: the quality of the encapsulation including its material, the machining process, the design of gaskets, the sealing material itself, and the factory testing procedures are of major importance; and
- b) very low handling losses: smaller gas compartments, reduced maintenance frequency, more sophisticated tools and instruments to handle and to check the gas quality, and specific training of designated personnel.

In addition to the above, the procedure of installation, service, maintenance, repair and proper disposal is described by the manufacturer in as detailed a manner as possible. Specially trained personnel should carry out the practical work.

### **0.10 Pressure systems**

#### **0.10.1 Controlled pressure systems**

These comprise a volume automatically replenished from an external or internal gas source. The volume could consist of several permanently connected gas-filled compartments. Controlled pressure systems are no longer used in new equipment because of their high leakage rate. For this reason, it is recommended that controlled pressure systems in old equipment be replaced by closed pressure systems.

#### **0.10.2 Closed pressure systems**

These comprise a volume replenished only periodically by manual connection to an external gas source. High-voltage SF<sub>6</sub> single pressure circuit-breakers are examples of closed pressure systems.

In spite of the fact that state-of-the-art HV electric power equipment is a closed pressure system, the typical time between two consecutive maintenance operations is approximately 25 years. In practice, on-site SF<sub>6</sub> handling is already minimized, as it is only required for installation, and extension or end-of-life-disposal/dismantling of equipment (or both). It is recommended that

- a) the leakage rate be kept lower than 0,5 % per annum per gas compartment,
- b) the typical time between two consecutive maintenance operations be up to 25 years,
- c) the SF<sub>6</sub> conditions be checked only after a filling operation, and
- d) appropriate record-keeping procedures be used.

In order to operate safely, switchgear needs a minimum gas pressure/density. If the gas pressure/density reaches its minimum threshold, standard operations can no longer be maintained and, according to specific user requirements, appropriate counter-measures (such as alarm, automatic lockout and switching features) come into effect.

Common gas-monitoring systems provide an alarm or indication when 5 % to 10 % of the gas has been released. The system has been designed to operate safely under these conditions, and still keeps a safety margin. In the case of compartments containing a small amount of gas, the impact on the environment is very small. On the other hand, in the case of large compartments (such as long busbar ducts), the amount of gas released before the threshold is reached is significant for the environment.

Therefore it is recommended that the gas pressure/density of each compartment be monitored, whenever technically feasible, to enable early detection of small leaks.



SF<sub>6</sub> should be handled in a closed cycle, to avoid any deliberate release to the environment. Among all the voluntary initiatives, gas recovery and recycling have the highest priority.

### **0.10.3 Sealed pressure systems**

These comprise a volume for which no further gas or vacuum processing is required during the expected operating life of the equipment. Sealed pressure systems are completely assembled and tested in the factory.

State-of-the-art MV electric power equipment is an example of a sealed pressure system. Such equipment is commercially designated “sealed for life”, as it requires no on-site gas handling during its life, which is typically 40 years. End-of-life disposal is the responsibility of the user with the support of the manufacturer. Third parties, such as service companies, may also carry out end-of-life disposal.

As SF<sub>6</sub> is handled only twice (for gas filling at the beginning and for gas recovery at the end) during the whole product life and this is done in a controlled environment, handling losses can be considered to be of the same order of magnitude as leakage losses. Today a typical leakage rate is lower than 0,1 % per annum per gas compartment.

### **Keywords**

sulfur hexafluoride, switchgear, global warming, environmental impact.

**NRS 087:2008**

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# GUIDELINES FOR THE MANAGEMENT OF SF<sub>6</sub> (SULFUR HEXAFLUORIDE) FOR USE IN ELECTRICAL EQUIPMENT

## 1 Scope

This specification covers provisions for the purchase, storage, management, handling and safe disposal of new, used, in-service, and contaminated SF<sub>6</sub> gas and its decomposition by-products for use in electrical equipment for dielectric and arc-quenching purposes.

## 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced documents (including any amendments) applies. Information on currently valid national and international standards can be obtained from the SABS Standards Division.

IEC 60376:2005, *Specification of technical grade sulfur hexafluoride (SF<sub>6</sub>) for use in electrical equipment*.

IEC/TR2 62271-303, *High-voltage switchgear and controlgear – Part 303: Use and handling of sulphur hexafluoride (SF<sub>6</sub>)*.

SANS 1091, *National colour standard*.

SANS 1518, *Transport of dangerous goods – Design, construction, testing, approval and maintenance of road vehicles and portable tanks*.

SANS 10019, *Transportable containers for compressed dissolved and liquified gases – Basic design, manufacture, use and maintenance*.

SANS 10228, *The identification and classification of dangerous goods for transport*.

SANS 10231: 2006, *Transport of dangerous goods – Operational requirements for road vehicles*.

SANS 10232-1, *Transport of dangerous goods – Emergency information systems – Part 1: Emergency information system for road transport*.

SANS 10263-2, *The warehousing of dangerous goods – Part 2: The storage and handling of gas cylinders*.

## Terms, definitions and abbreviations

For the purposes of this document, the following terms, definitions and abbreviations apply.

### 3.1 Terms and definitions

#### **class 1 cylinder**

seamless metallic container

#### **contaminated gas**

gas that is impure or unclean by contact or mixture and that is not deemed suitable for use in electrical equipment

**electrical equipment**

equipment that is used for such purposes as generation, conversion, transmission, distribution or utilization of electrical energy

NOTE Machines, transformers, apparatus, measuring instruments, protective devices, wiring materials and appliances are examples of electrical equipment.

**final disposal**

transformation of gas into substances which can either be used for other purposes or be disposed of in an environmentally compatible way

**global warming**

increase in the average temperature worldwide

NOTE Global warming is believed to be caused by the greenhouse effect.

**handling**

process which might involve contact of workers with new or used SF<sub>6</sub>

NOTE This process includes removing the gas from an item of switchgear or controlgear either completely or as a sample to be tested, opening a gas-filled enclosure, cleaning out an open enclosure and working inside large enclosures.

**heavily arced gas**

gas recovered from equipment in which failure arcing has occurred

NOTE In this case, high levels of solid and gaseous contaminants can be expected.

**insulating gas**

gas with negligible low electric conductivity, used to separate conducting parts of different electrical potentials

NOTE This could be used sulfur hexafluoride, i.e. SF<sub>6</sub> that has been introduced into electrical equipment, or unused sulfur hexafluoride, i.e. SF<sub>6</sub> that has never been introduced into electrical equipment (for example gas that has been transferred into a storage tank).

**leakage**

unplanned, usually continuous, emission of gas from a sealed or closed system

NOTE Leakage occurs at seals and joints and by molecular diffusion through certain enclosure materials. Leakage does not include releases of gas due to intervention with the systems intended to contain it.

**maintenance**

combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function

**new gas**

technical grade SF<sub>6</sub> that complies with IEC 60376

**non-arced gas**

gas that has not experienced arcing

NOTE The major contaminants in non-arced gas could be air (mainly introduced by handling) and moisture (mainly desorbed from inner surfaces). Small quantities of reactive gaseous decomposition by-products (typically in the 100 µL/L (100 ppmv) range) might also be present when strong partial discharges have occurred in the gas and no absorbers were provided.

**normally arced gas**

gas recovered from switchgear compartments after normal switching operations

**reclaimer**

device for the purification of used gas for the purpose of reuse on site

**reclaiming**

elimination of soluble and insoluble contaminants from an insulating liquid or gas by chemical adsorption means, in addition to mechanical means, to restore properties as close as possible to the original values

**recovery**

transfer of gas from electric power equipment into a reclaimer or storage container

**recycling**

operation to pass through a series of changes or treatment so as to return to a previous stage in a cyclic process

**reusable gas**

gas that is not new but that is suitable for reuse in electrical equipment

**toxic gas**

gas containing by-products that might, in sufficient quantities, be harmful or deadly to human life

## 3.2 Abbreviations

<b>GWP</b>	:	global warming potential
<b>PPE</b>	:	personal protective equipment
<b>ppmv<sup>1)</sup></b>	:	parts per million volume
<b>ppmw<sup>1)</sup></b>	:	parts per million weight
<b>SCBA</b>	:	self-contained breathing apparatus
<b>SF<sub>6</sub></b>	:	sulfur hexafluoride

## 4 Requirements

### 4.1 Management of SF<sub>6</sub>

The owner of the SF<sub>6</sub> electric power equipment is responsible for the proper use, transportation, and disposal of both the equipment and the gas. He is also responsible for the yearly record-keeping of SF<sub>6</sub> stored in equipment or cylinders (or both) and also for emission rates. The equipment manufacturer and the gas producer provide basic information for this purpose.

Therefore an SF<sub>6</sub> management system shall be put in place and owners shall be responsible for the following:

- a) formulation of a documented policy appropriate to the management of SF<sub>6</sub> as new, in-service, decomposition by-products and contaminated gas used during storage and disposal;
- b) delegation of responsibilities for key functions, including quality assurance and safety, health and environment;

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1) In keeping with international standards, the equivalent SI units have been used, i.e. µg/g (to show ppmw) or µL/L (to show ppmv).

- c) ensuring that all staff who work with SF<sub>6</sub> are trained and fully competent in the proper handling and filling of cylinders/vessels and are aware of the associated risks and the effect of SF<sub>6</sub> on the environment;
- d) provision of resources to ensure a safe and hygienic work environment;
- e) keeping an inventory (in kilograms) on SF<sub>6</sub> purchasing, usage and disposal (see annex D for an example of a typical SF<sub>6</sub> reporting form);
- f) identification of all plants containing SF<sub>6</sub>;
- g) display of adequate signage in all facilities and installations where SF<sub>6</sub> gas is utilized; and
- h) emergency preparedness plans and clean-up procedures.

## 4.2 Categories of SF<sub>6</sub>

Based on the nature and the quantity of contaminants (all SF<sub>6</sub> contains contaminants), the following gas categories can be defined:

- a) new gas or technical grade gas, for example SF<sub>6</sub> that complies with IEC 60376 and table 3 of this specification;
- b) SF<sub>6</sub> deemed suitable for reuse, for example reclaimed gas that complies with table 4 of this specification and suitable for
  - 1) a complete range of useful pressures (< 850 kPa, i.e. all HV and MV equipment), and
  - 2) the low range (< 200 kPa, i.e. MV equipment); and
- c) SF<sub>6</sub> deemed unsuitable for reuse (contaminated), i.e. gas that does not comply with this specification for used gas, that is heavily contaminated and that requires further treatment, usually off site or eventually final disposal (or both, see 4.9).

**Table 3 — Table of purity for new SF<sub>6</sub> gas**

1	2
Gas	IEC 60376 specifications
SF <sub>6</sub>	≥ 99,70 % by mass
Air	≤ 500 µg/g (500 ppmw)
CF <sub>4</sub>	≤ 500 µg/g (500 ppmw)
H <sub>2</sub> O	≤ 15 µg/g (15 ppmw)
Mineral oil	≤ 10 µg/g (10 ppmw)
Acidity, in terms of HF	≤ 0,3 µg/g (0,3 ppmw)
Hydrolysable fluorides, in terms of HF	≤ 1 µg/g (1 ppmw)



**Table 4 — Table of purity for re-useable SF<sub>6</sub> gas**

1	2	3
Impurity	Maximum acceptance levels	
	Rated absolute pressure ≤ 200 kPa <sup>a</sup>	Rated absolute pressure > 200 kPa <sup>a</sup>
Air or CF <sub>4</sub> (or both)	3 % volume <sup>b</sup>	3 % volume <sup>b</sup>
H <sub>2</sub> O	95 mg/kg <sup>c,d</sup>	25 mg /kg <sup>d,e</sup>
Mineral oil	10 mg/kg <sup>f</sup>	10 mg /kg <sup>f</sup>
Total reactive gaseous decomposition by-products	50 µL/L total or 12 µL/L for (SO <sub>2</sub> + SOF <sub>2</sub> ) or 25 µL/L for HF	
<sup>a</sup> Within the complete range of reuse pressures, covering all possible applications (both HV and MV insulation systems and all circuit-breakers), the low reuse pressure range $p \leq 200$ kPa has been defined to highlight low pressure insulation systems (typically applied in MV distribution).		
<sup>b</sup> In the case of SF <sub>6</sub> mixtures, the level of CF <sub>4</sub> shall be specified by the equipment manufacturer.		
<sup>c</sup> 95 mg/kg (95 ppmw) is equivalent to 750 µL/L (750 ppmv) and to a dew point of -23 °C, measured at 100 kPa and 20 °C.		
<sup>d</sup> Converted to millilitres per litre, these levels shall also apply to mixtures until a suitable standard becomes available.		
<sup>e</sup> 25 mg/kg (25 ppmw) is equivalent to 200 µL/L (200 ppmv) and to a dew point of -23 °C, measured at 100 kPa and 20 °C.		
<sup>f</sup> If gas-handling equipment (pump, compressor) containing oil is used, it might be necessary to measure the oil content of the SF <sub>6</sub> . If all equipment in contact with the SF <sub>6</sub> is oil-free, then it is not necessary to measure the oil content.		

### 4.3 Identification of gas cylinders for categories of SF<sub>6</sub>

The labelling of gas cylinders and cylinder colour identification shall be done in accordance with the requirements of SANS 1091 and SANS 10019.

### 4.4 Purchasing of SF<sub>6</sub>

#### 4.4.1 Introduction

Subclause 4.4 is intended to guide the users and suppliers of SF<sub>6</sub>-insulated equipment on the purchase and supply of new SF<sub>6</sub> gas. This relates to the quality of new gas to be used.

#### 4.4.2 New gas specification

The minimum quality of new SF<sub>6</sub> gas to be used in SF<sub>6</sub>-insulated equipment is detailed in table 1 of IEC 60376:2005, as shown in table 3.

#### 4.4.3 Quality control

Management procedures and processes shall be established and implemented to ensure that the SF<sub>6</sub> purchased meets users' minimum requirements. A test certificate by a SANAS-approved certification body proving compliance with the above shall be issued for each cylinder. Where batch testing is conducted, traceable cross-referencing to the individual cylinders shall be included.

## 4.5 Reusable gas specification

### 4.5.1 Maximum acceptance impurity levels for reuse of SF<sub>6</sub> gas

The minimum quality of reusable SF<sub>6</sub> gas to be used in SF<sub>6</sub>-insulated equipment is detailed in IEC 60480, as shown in table 4.

### 4.5.2 Decision flow chart for SF<sub>6</sub> gas removed from electrical equipment for treatment

As a guide for the operator, the flow chart in figure 1 defines the selection procedure to determine the best use of SF<sub>6</sub> after it has been removed from equipment for potential treatment.

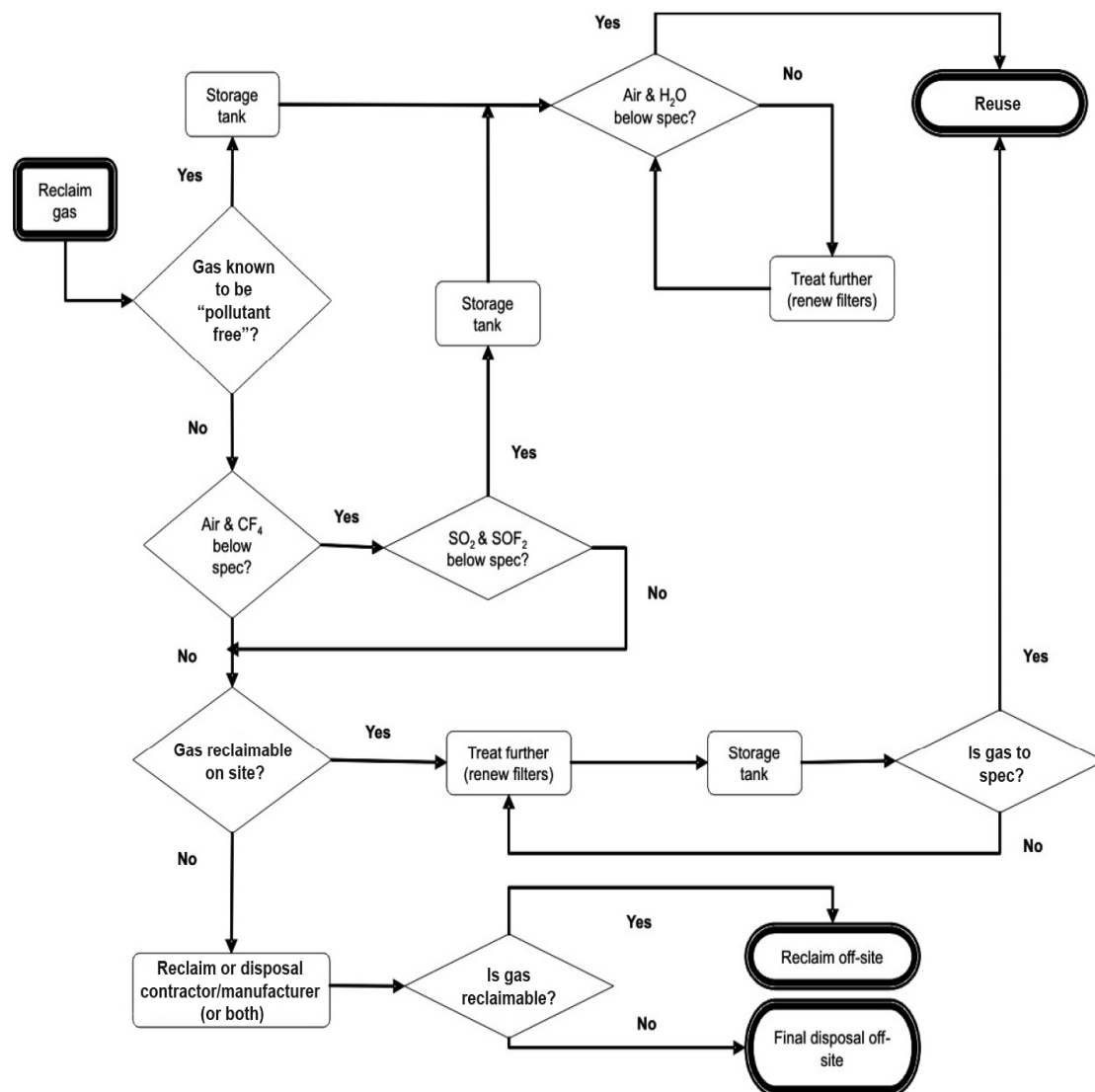


Figure 1 — Decision flow chart for destination of removed SF<sub>6</sub> gas

## **4.6 Handling**

### **4.6.1 General**

The need to handle SF<sub>6</sub> arises

- a) when the gas is introduced to, or reclaimed from, electrical equipment,
- b) during storage,
- c) during transportation, and
- d) during disposal.

### **4.6.2 Gas handling**

#### **4.6.2.1 General**

Particular care shall be taken to prevent contamination of SF<sub>6</sub> when it is transferred to or from the electrical equipment or during testing and storage, or both.

When used SF<sub>6</sub> has to be removed from an enclosure, caution shall be taken to prevent any avoidable release of the gas into the atmosphere and in particular into the work area.

Proper, purpose-built and maintained gas recovery/handling equipment shall be used wherever possible to allow the gas to be stored, usually under pressure. Such equipment should be capable of evacuating the enclosure to remove as much of the gas as possible. Gas recovery equipment is available which is specially designed for use with SF<sub>6</sub> and is provided with reclaiming facilities for removing gaseous and solid decomposition by-products. This type of equipment is preferred, particularly for the removal of more heavily contaminated SF<sub>6</sub>, for example from circuit-breaker enclosures.

#### **4.6.2.2 Gas-handling procedure**

When SF<sub>6</sub> gas has to be transferred into, or removed from, an enclosure, a proper handling procedure shall be defined and implemented to limit any release of SF<sub>6</sub> into the environment wherever possible.

To control the quality and wastage of the gas, the following electrical equipment features and gas-handling equipment are recommended as a guideline (see annex E):

- a) closed-loop systems;
- b) sealed systems that are designed to withstand both pressure and vacuum;
- c) internal absorbers to keep contamination levels in the gas very low and to ease the cleaning of the gas during recycling;
- d) subdivision of the equipment in closed compartments to limit the quantity of the gas to be recycled, particularly in the case of failure arcing when severely contaminated SF<sub>6</sub> has to be treated;
- e) SF<sub>6</sub>-specific gas connections and check valves to prevent accidental gas loss or contamination with air by handling errors;
- f) the minimization of external gas pipe-work to reduce leakage (from corrosion) or mechanical damage;

- g) the minimization of the use of oil and grease as lubricants in the equipment to exclude the possibility of contamination in the gas with lubricant oil, which is difficult to remove;
- h) SF<sub>6</sub> vacuum/compressor unit (vacuum min. 5 mbar);
- i) pre-filter unit;
- j) correct filling equipment adaptors;
- k) suitable, non-permeable and sealable extraction and filling hoses (preferably sealed by means of non-return valves on each end);
- l) gas leak detector;
- m) appropriate regulators with accurate gauges;
- n) calibrated pressure gauge (preferably absolute pressure);
- o) thermometer and pressure/temperature tables;
- p) calibrated test equipment (dew point and purity) and decomposition detector tubes;
- q) correct and appropriate documentation, procedures, manufacturers' instructions, safety instructions, etc.;
- r) appropriate tools, cleaning equipment, safety equipment, etc.; and
- s) assurance that all dust/moisture caps/protectors etc. are sound and in place when equipment is not in use.

#### 4.6.2.3 Impurities from handling and in service

The quality of SF<sub>6</sub> gas can easily be compromised by impurities during handling. Moisture can even be desorbed from internal surfaces of the equipment and from polymeric parts. Oil from handling equipment (pumps and compressors) might also inadvertently be introduced into SF<sub>6</sub> gas.

Caution should be exercised when equipment is filled and emptied, as failure to do so might lead to the addition of air, dust and water vapour.

**WARNING:** To maintain the di-electric strength, purity, dryness and cleanliness when maintenance work is carried out on open circuit-breakers and associated equipment, it should be noted that not only dirt but also air, humidity and sweaty hands can cause damage to equipment.

#### 4.6.2.4 Freezing

If compressed SF<sub>6</sub> is released rapidly, its subsequent sudden expansion reduces its temperature. The gas temperature could fall well below 0 °C.

A person who is accidentally subjected to a jet of gas, during equipment filling for example, runs the risk of serious freeze burns, if not equipped with protective clothing and eye protection. Liquid SF<sub>6</sub> is particularly hazardous in this regard.

**WARNING:** The filling of SF<sub>6</sub> should always be performed slowly. Personnel should be aware of the danger of freeze burns when touching iced or frozen metal parts (or both). The heating of cylinders, when the apparatus is being filled, should preferably be avoided. Only thermostatically controlled devices approved by a SANAS-approved certification body shall be used for this purpose.

### 4.6.3 Handling of cylinders

#### 4.6.3.1 General

Cylinders shall not be subjected to any undue shock. They shall be handled safely and carefully. Sliding, rolling and skidding shall be avoided.

#### 4.6.3.2 Storage

Cylinders shall be inspected, stored and used in accordance with the requirements set out in the relevant national legislation and SANS 10263-2.

In addition, the following requirements shall be met:

- a) Cylinders shall be stored in a dry place and away from boilers, open flames, steam pipes and any other source of heat or potential source of heat, which shall be clearly demarcated for the purpose.
- b) Cylinders shall not be exposed to corrosive vapours.
- c) Cylinders shall not be stored with other cylinders that contain flammable materials.
- d) In view of the possibility of leakage as a result of minor defects and of possible asphyxiation, cylinders shall be stored in suitably ventilated areas. Care shall be taken to ensure that drains or trenches (or both) do not create pockets in which gas might collect.
- e) Leaking cylinders, where the leak cannot be stopped quickly and easily, shall be removed to an open space where they will offer minimum danger to life and property, and appropriate measures shall be taken to rectify the situation.
- f) Full or partially full cylinders shall be stored in a vertical position, resting on their footings or specially formed bases in single tier rows, arranged in groups, each containing up to four rows of cylinders, with gangways between groups.
- g) Empty cylinders should preferably be stored in a vertical position but may be stored horizontally. When empty cylinders are stored horizontally, they shall be in single rows or in groups comprising two rows with the valves adjacent to the gangways. The ends of each horizontal row shall be securely wedged.
- h) Gangways shall be maintained between stacks, walls and fences.
- i) When pallets or baskets are used, they shall be placed in single rows with gangways between the rows.
- j) Cylinders that contain contaminated SF<sub>6</sub> gas shall be stored in a totally separate, demarcated and restricted storage area.
- k) All cylinder valve caps/protectors shall be in place and all cylinders shall be stored in such a way that valves cannot be inadvertently damaged.
- l) All required signage shall be included at all storage locations.
- m) Cylinders for new gas shall not be used for storage of used SF<sub>6</sub> gas.

NOTE A 90-day temporary storage licence is required from the relevant authority (see foreword) for waste gases awaiting disposal. In accordance with environment conservation legislation (see foreword), an exemption may be applied for.

#### 4.6.3.3 Transportation of SF<sub>6</sub> gas in class 1 cylinders and vessels

Transportation shall be carried out in accordance with dangerous goods legislation (see foreword). Vehicles and transportation operations shall also comply with the national standards SANS 10231 and SANS 10232-1. See table 5.

**Table 5 — Transportation requirements for various grades of SF<sub>6</sub>**

1	2	3	4
Category	Description	Quantity	References
New SF <sub>6</sub>	SF <sub>6</sub> complying with IEC 60376	≤ 500 kg > 500 kg	Exempt from legislation; Legislation; SANS 10228
Reusable SF <sub>6</sub>	Reclaimed and suitable for reuse	≤ 500 kg > 500 kg	Exempt from legislation; Legislation; SANS 10228
Contaminated SF <sub>6</sub>	Not suitable for reuse, e.g. corrosive	All quantities	Legislation; SANS 10228
Toxic SF <sub>6</sub>	Not suitable for reuse, e.g. toxic and corrosive	All quantities	Legislation; SANS 10228
NOTE New SF <sub>6</sub> and reusable SF <sub>6</sub> are considered to be class 2.2, and contaminated gas is classified as class 2.3 in terms of "classes of dangerous goods" in legislation (see foreword).			

The transportation of small quantities (≤ 500 kg) of SF<sub>6</sub> is exempt from legislation (see foreword). The 500 kg exemption only applies to a single load of SF<sub>6</sub>. Requirements for load compatibility and exempt quantities of mixed loads are given in SANS 10232-1. (As a rule of thumb, a load consisting of three 63 kg cylinders of SF<sub>6</sub>, one 12 kg cylinder of oxygen, one 8 kg cylinder of acetylene and one 19 kg cylinder of LPG is exempt from legislation (see foreword).

### 4.7 Load constraints

#### 4.7.1 Exempt quantity for a load that consists of a single dangerous goods item

A list of dangerous goods listed by UN No. and hazard class, together with the relevant exempt quantity, is given in annex C of SANS 10231:2006. All the requirements of the regulations promulgated in terms of legislation (see foreword) shall apply when goods in excess of the exempt quantity are transported.

#### 4.7.2 Calculation of exempt quantity A for a multiload

If no single item of dangerous goods in the multiload (see 4.7.3) exceeds the quantity (in kilograms or litres, as applicable) given in column 6 of table C.1 of SANS 10231:2006, the calculation below shall be done for each item of dangerous goods in the load.

If the sum of A for all the calculations does not exceed 1 000, the requirements of SANS 10231:2006 do not apply.

If the total exceeds 1 000, the vehicle shall comply with all the requirements of the regulations of legislation (see foreword).

$$A = Q \times F$$

where

A is the exempt quantity;

Q is the quantity being transported (in kilograms or litres, as applicable);

F is the factor shown in column 7 of table C.1 of SANS 10231:2006.

### 4.7.3 Load compatibility

A load that consists of more than one hazard is called a mixed load or a multiload and may only be transported if the goods or substances on the load are compatible.

In the case of a multiload, the load shall comply with the requirements of the compatibility chart given in annex G of SANS 10231:2006.

### 4.8 General transportation (for SF<sub>6</sub> quantities not exempt from legislation (see foreword))

A vehicle assigned for the transportation of SF<sub>6</sub> gas cylinders shall comply with SANS 1518 to ensure that the vehicle complies with the design requirements for the transportation of dangerous goods.

Where compliance with legislation and with SANS 10228 is required (see table 5), vehicles transporting contaminated SF<sub>6</sub> gas cylinders shall comply with relevant hazardous waste legislation and shall carry the required documentation. Safety checks shall be performed on the vehicle and crew (driver and assistants) before commencement of the trip. These checks shall include, but not be limited to, the following:

- a) vehicle and driver licensing;
- b) tremcard (Transport Emergency Card);
- c) driver's medical history;
- d) spill kit and safety gear;
- e) driver training;
- f) vehicle roadworthiness;
- g) HAZCHEM vehicle signs;
- h) route map;
- i) waste manifesto;
- j) dangerous goods declaration; and
- k) emergency response contact list.

Cylinders transported in a vehicle shall be so blocked or braced (or both) as to prevent movement, and shall not project beyond the sides or ends of the vehicle. There shall be no sharp projections on the inside of the loading space, and adequate measures shall be taken to prevent cylinders from falling off the vehicle.

All full SF<sub>6</sub> cylinders and those that contain residual gas shall be stacked in a vertical position during transportation.

Multiload (mixed-load) cylinders shall be transported in accordance with the regulations in legislation (see foreword) and in accordance with SANS 10232-1 to establish compatibility of loads when cylinders or goods of a different nature are transported with SF<sub>6</sub> cylinders.

Specific labelling of containers shall be effected in accordance with SANS 1091 and with the relevant national and international regulations.

## 4.9 Disposal of contaminated gas and solid decomposition by-products

**4.9.1** All disposal shall be undertaken in accordance with national legislation (see foreword). See annex F.

The owner of the hazardous waste shall be responsible for its safe disposal.

**4.9.2** The following are preferred safe disposal methods:

- a) return to the manufacturer; and
- b) incineration. At the end of its useful life (i.e. when it is no longer technically and economically recyclable), SF<sub>6</sub> can be destroyed by incineration in compliance with local regulations.

**4.9.3** SF<sub>6</sub> waste shall only be treated or disposed of (or both) by a licensed facility of the relevant authority (see foreword) and through processes which minimize the release of SF<sub>6</sub> and its by-products into the environment. The disposal facility shall supply proof of a valid licence to the waste owner for record-keeping purposes.

**4.9.4** The disposal facility operator shall issue a safe-disposal certificate to the waste owner. The safe-disposal certificate shall indicate the name of the waste owner, the quantity of SF<sub>6</sub> disposed of, the date of the disposal, and the disposal facility's name and licence number. A register of completed safe-disposal certificates shall be kept and maintained by the waste owner for a minimum period of five years.

## 5 Tests

### 5.1 General

Methods for analysis of SF<sub>6</sub> shall be based on gas samples to determine and to monitor the quality of the new, in-service and used gas. Annex E provides details on how to check the quality of SF<sub>6</sub> and to detect its by-products, i.e. reactive and non-reactive gases.

The following SF<sub>6</sub> gas tests and measurements are recommended to monitor the quality of the new and used gas:

- a) the percentage of SF<sub>6</sub> gas in the equipment;
- b) the measurement of decomposition by-product concentrations; and
- c) the measurement of the dew point of the SF<sub>6</sub> gas (humidity).

### 5.2 On-site analysis

These methods are intended to be quick and simple gas-screening tests and the following order of analysis has been set to determine, as quickly as possible, whether the gas is reusable or reclaimable on site (see figure 2).

If on-site analysis systems are available, the specification requires the use of the smallest possible amount of SF<sub>6</sub>, to avoid any release of SF<sub>6</sub> to the atmosphere, and to ensure the health and safety of personnel. The order of the gas-screening analysis is shown in table 6 and figure 2. Sampling shall be carried out in accordance with annex G.

For all on-site analysis, the operator shall follow the manufacturer's instructions concerning the accuracy of analytical equipment.



The analysis for SO<sub>2</sub>, SOF<sub>2</sub> and HF is required for two reasons: firstly for safety, to allow personnel to assess the risk involved in handling used SF<sub>6</sub>, and secondly to protect the analytical equipment against corrosion.

**Table 6 — On-site SF<sub>6</sub> gas-screening analysis methods**

1	2	3
Order of analysis	Impurities	Methods available
1	Decomposition by-products: SO <sub>2</sub> , SOF <sub>2</sub> , SO <sub>2</sub> F <sub>2</sub> <sup>a</sup>	Tube for SO <sub>2</sub> + SOF <sub>2</sub> Portable gas chromatograph with thermal conductivity detector (GC-TCD)
2	HF	Tube for HF
3	Air and CF <sub>4</sub>	Density meter (for the percentage of SF <sub>6</sub> ) Portable GC-TCD
4	H <sub>2</sub> O (moisture)	Tube for water Electronic hygrometer Chilled mirror hygrometer Electrochemical sensor
5	Oil	Tube for mineral oil
<sup>a</sup> SO <sub>2</sub> F <sub>2</sub> might be present in the gas but cannot be measured with detector tubes. To ensure the removal of this by-product, see annex E.		

### 5.3 Laboratory analysis

If no equipment is available on site, the following recommended techniques should be used. Laboratory analysis is intended to provide a quantitative assessment of the impurities in a gas sample.

Water is the only contaminant that cannot be determined accurately from a sampling cylinder. The water content of a sample in a cylinder taken from a reservoir is not representative of the water content in the reservoir because water adsorbs on all surfaces. Therefore, the water analysis should always be carried out directly on the reservoir on site. There is no recommended order of analysis. See table 7.

**Table 7 — Laboratory analysis of SF<sub>6</sub> gas**

1	2
Impurities	Methods available
Air: oxygen and nitrogen	Gas chromatograph with thermal conductivity detector (GC-TCD)
CF <sub>4</sub>	Gas chromatograph (GC-TCD) Infrared absorption
Oil	Infrared absorption Gas chromatograph with flame ionization detector (GC-FID)
Decomposition by-products SO <sub>2</sub> , SOF <sub>2</sub> , SO <sub>2</sub> F <sub>2</sub> , SF <sub>4</sub> , HF	Gas chromatograph (GC-TCD) Ion chromatography Infrared absorption

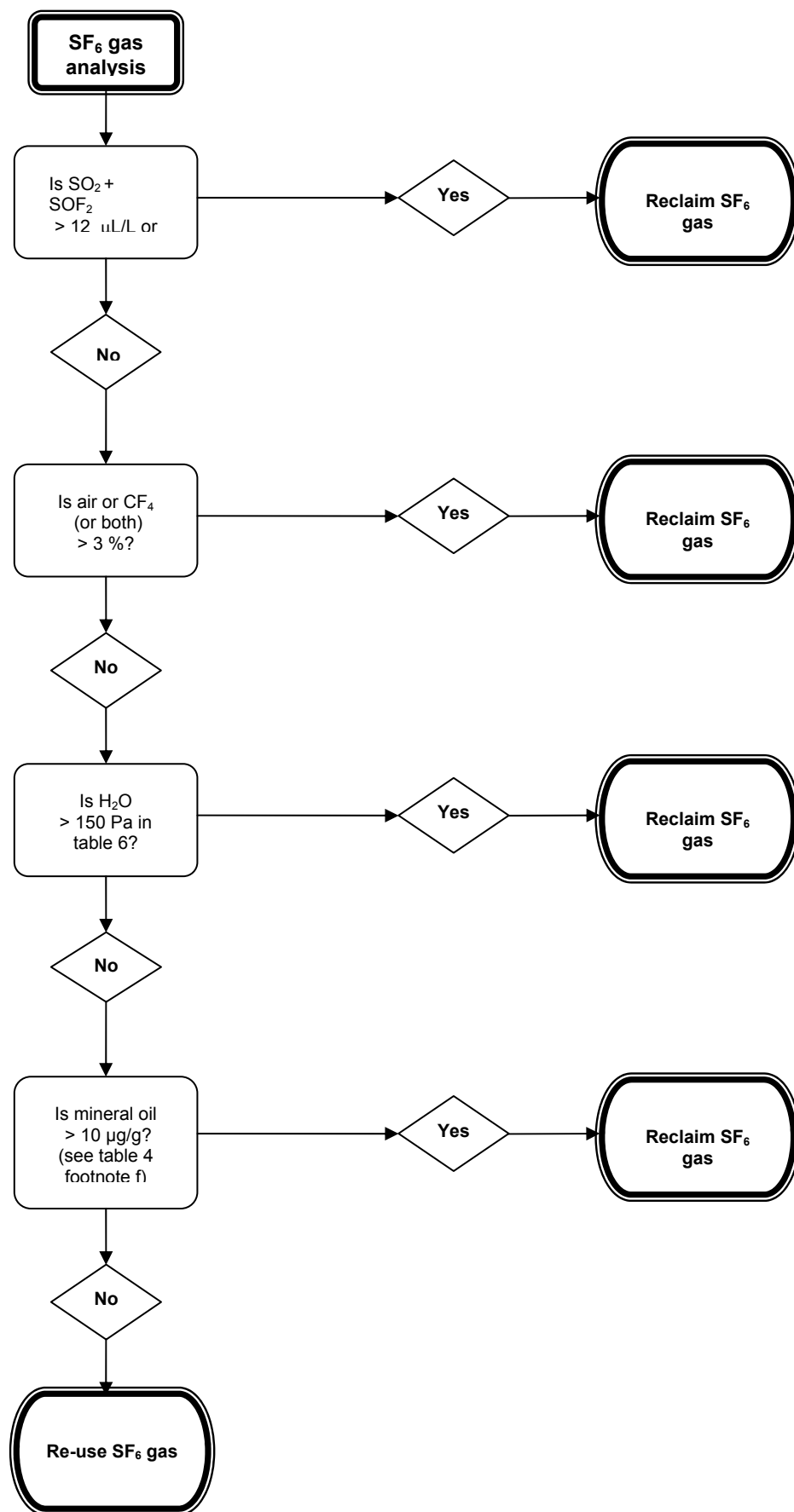


Figure 2 — Decision flow chart for on-site SF<sub>6</sub> gas-screening analysis

## 6 Training

Work involving SF<sub>6</sub> handling (manufacturing, testing, erection, commissioning, maintenance, service, and dismantling at the end-of-life) shall be performed either by trained personnel or by personnel under the supervision of trained personnel in accordance with the operating instruction manual from the original equipment manufacturer (with regard to electric power equipment, tools, instruments, etc.) and data sheets (for example SF<sub>6</sub>, cleaning agents).

Specific safety training shall be given to personnel required to handle used SF<sub>6</sub>. Personnel shall be trained in the use of SF<sub>6</sub> handling equipment used to transfer gas from an enclosure into a storage vessel, and the manufacturer's operating instructions for such equipment should be complied with whenever it is used.

Training shall consist of both theoretical and practical sessions and should, as a guideline, include the following where appropriate:

a) SF<sub>6</sub>:

- 1) physical/chemical/environmental characteristics of SF<sub>6</sub>;
- 2) application of SF<sub>6</sub>, used in electric power equipment (insulation, arc quenching);
- 3) standards;
- 4) personnel safety: asphyxiation, contamination, gaseous and solid decomposition by-products;
- 5) environmental impact; and
- 6) disposal of SF<sub>6</sub> and its gaseous or solid decomposition by-products (or both);

b) electric power equipment:

- 1) design and functionality;
- 2) SF<sub>6</sub> handling on site during erection, commissioning, maintenance, and dismantling at the end-of-life;
- 3) benefits of SF<sub>6</sub> technology in electric power equipment;
- 4) troubleshooting of electric power equipment utilizing SF<sub>6</sub>; and
- 5) working under fault conditions;

c) handling of SF<sub>6</sub> in electric power equipment:

- 1) evacuation of gas compartment;
- 2) filling of gas compartment;
- 3) recovery, reclaiming, storage and transportation of SF<sub>6</sub>;
- 4) handling of maintenance equipment;
- 5) working on open gas compartments; and
- 6) checking the gas quality;

d) it is not considered necessary for such workers to have any pre-qualifying training or qualifications;

- e) first-aid instructions shall be included in the safety training; and
- f) records of training shall be kept.

## **7 Safety**

### **7.1 Safety precautions**

Personnel engaged in handling used SF<sub>6</sub> shall be provided with personal safety equipment (gloves, safety glasses, etc.). The manufacturer's instructions and users' codes of practice shall specify which items of equipment are required for each situation. Annex H sets out requirements for the use of a respirator and protective clothing.

Personnel handling used SF<sub>6</sub> shall be familiar with the properties of SF<sub>6</sub> decomposition by-products and shall be aware of the risks to health (for example contact, inhalation, etc.) and the cautions necessary to minimize them.

Guidance on working safely with SF<sub>6</sub> is required in order to anticipate the following hazards:

- a) oxygen depletion;
- b) freezing; and
- c) exposure to decomposition by-products.

In many applications the pressure of SF<sub>6</sub> gas employed is above atmospheric pressure. This implies that special precautions have to be taken when the equipment is handled, to avoid exposing personnel to the risks associated with mechanical failure of the enclosure walls. All equipment and tools used during SF<sub>6</sub> handling should be handled with extreme caution.

### **7.2 Protective equipment and measures**

#### **7.2.1 General**

For the handling of SF<sub>6</sub> gas and its decomposition by-products, the following protective measures shall be taken as depicted in table 8.

#### **7.2.2 Protection of staff**

The type of protection and its extent depend on the category of the gas in the compartment. Details are given in table 9.

#### **7.2.3 Personal hygiene**

Eating, drinking and smoking are not allowed when personnel access/enter an open gas compartment. It is recommended that clothes should be changed and the skin washed to prevent the potential danger of irritation or burns.

#### **7.2.4 Protection of the environment**

It is recommended that all cleaning materials be neutralized before disposal.

Procedures for contaminated and toxic gases shall be adhered to.

All contaminated equipment shall be neutralized before disposal or being returned to service.

**Table 8 — General measures when working with SF<sub>6</sub> switchgear**

1	2	3	4
Item	Work in the vicinity of switchgear (operation of SF <sub>6</sub> switchgear, visual check, room cleaning)	Filling, recovering, evacuation of SF <sub>6</sub> gas compartments	Opening of SF <sub>6</sub> gas compartments, work on open compartments
SF <sub>6</sub> material safety data sheet/operational manuals <sup>a</sup>	—	Mandatory	Mandatory
Training	Mandatory	Mandatory	Mandatory
Gas-handling equipment	—	Mandatory	Mandatory
Cleaning/neutralizing equipment	—	—	Mandatory
Personal protection equipment	—	—	Mandatory
Flames	—	Not allowed	Not allowed
Welding/smoking	—	Not allowed	Not allowed
Drinking/eating	—	—	Not allowed
<p>General information should be specified according to the type of work and installation.</p> <p>It is recommended that the oxygen content in the gas compartment be measured prior to personnel entering/accessing. In addition to that, personnel may check the oxygen content in the ambient environment when working in confined spaces.</p> <p>Switching dust, which might be present inside the gas compartment after opening, and the absorbers (or filters) contain acidic compounds and shall be treated as special chemical waste in accordance with local regulations. This also applies to any tool/equipment/clothing (such as vacuum cleaners, cleaning paper and protective clothes) which has been in contact with the switching dust.</p>			
<sup>a</sup> See annex I.			

### 7.2.5 Handling of contaminated safety equipment/tools/clothing

Safety equipment/tools/clothing which has been in contact with switching dust or adsorbers (or both) shall be regarded as contaminated. They shall be collected afterwards and placed in plastics bags. The plastics bags shall be sealed with tape and labelled to indicate that the contents contain chemically contaminated items to be treated and, if necessary, disposed of in accordance with local regulations.

Reusable safety equipment or tools (or both) shall be washed and neutralized in an alkaline solution, for example, 10 % (by mass) sodium carbonate powder (Na<sub>2</sub>CO<sub>3</sub>) dissolved in water, and shall then be washed with clean water.

Single-use safety equipment or tools (or both) shall be placed in a plastics bag for further disposal in accordance with local regulations. They shall be regarded as special waste.

Recyclable PPE (overalls and goggles) is placed into the "Recycle" bin, and should be left to soak for 24 h in an alkaline solution as described above. Afterwards, it may be rinsed in clean water, and thereafter dried and reused in the normal manner.

**Table 9 — Safety at work when accessing/entering gas compartments in electric power equipment utilizing SF<sub>6</sub>**

1	2	3	4
Item	Open compartment before first SF <sub>6</sub> filling	Open compartment which contained new or non-arc'd SF <sub>6</sub>	Open compartment which contained either normally arc'd or heavily arc'd SF <sub>6</sub>
Potential risk	Fumes of cleaning material O <sub>2</sub> starvation Remaining SF <sub>6</sub> or other gas from production process	Fumes of cleaning material O <sub>2</sub> starvation Remaining gas	Fumes of cleaning material O <sub>2</sub> starvation Remaining gas Residual reactive gaseous decomposition by-products Switching dust and adsorbers
Safety precaution	Ventilation Measurement of O <sub>2</sub> concentration when entering	Ventilation Measurement of O <sub>2</sub> concentration when entering	Removal of switching dust and adsorbers Ventilation Measurement of O <sub>2</sub> concentration when entering Wearing of personal protective equipment
Safety equipment and tools	Suction ventilator or vacuum cleaner O <sub>2</sub> concentration measuring device	Suction ventilator or vacuum cleaner O <sub>2</sub> concentration measuring device	Suction ventilator or vacuum cleaner O <sub>2</sub> concentration measuring device Single-use protective clothes, shoe covers, hair cap Acid-proof safety gloves Full face respirator (preferred) or, at least, breathing protective mask Protective goggles

Disposal of both the alkaline solution and the washing water shall be done in accordance with local regulations.

Neutralizing kits comprising the following shall be made available:

- a) a plastics neutralizing container, with no lid;
- b) PPE: breathing mask, rubber gloves, protective suit;
- c) plastics spoon;
- d) alkaline solution, for example, sodium carbonate powder (Na<sub>2</sub>CO<sub>3</sub>); and
- e) plastics container for the alkaline solution.

### 7.3 Protective clothing and equipment

The following items should be available in quantities sufficient for operational and maintenance requirements:

- a) full face respirator with canister filter for protection against gas and dust, and that complies with the following:
  - 1) face piece (IEC/TR 62271-303);
  - 2) eye protection (IEC/TR 62271-303); and
  - 3) canister filter (IEC/TR 62271-303);
- b) disposable pocketless hooded non-permeable coveralls with elastic wrist grips;
- c) lightweight neoprene gauntlet type gloves;
- d) rubber boots as normal issue to staff;
- e) head protection in the form of safety helmets as normal issue to staff;
- f) eyewash bottles containing saline solution;
- g) first-aid equipment;
- h) cleaning materials, i.e. disposable wiping cloths;
- i) SF<sub>6</sub> gas-handling plant, including a portable vacuum pump with a disposable filter;
- j) vacuum cleaner with high efficiency exhaust filter and disposable bag, and that complies with IEC/TR 62271-303; and
- k) oxygen detector, i.e. a portable unit with visual and audible warning.

## **Annex A** (informative)

### **Design considerations for SF<sub>6</sub> recycling equipment**

#### **A.1 General**

As a general philosophy, the better the design and quality of the various components of an SF<sub>6</sub> reclaimer, the lower the probability of the introduction of undesirable contaminants into the SF<sub>6</sub> gas. An investment in good quality equipment can thus be justified by the elimination of high-cost special procedures, which might otherwise be required when SF<sub>6</sub> is recycled.

#### **A.2 Pre-filter for heavily arced SF<sub>6</sub> gas**

**A.2.1** Additional pre-filters are typically used between the SF<sub>6</sub> gas-processing unit and the SF<sub>6</sub>-insulated equipment in an attempt to keep contaminants of heavily arced gas from harming the processing equipment and from contaminating reclaimed SF<sub>6</sub> already stored in the gas cart's storage vessel.

**A.2.2** Pre-filter units should not contain ingredients that form stable gases rather than absorb SF<sub>6</sub> by-products. They should have self-sealing pressure connections and vacuum-tight connections on both input and output points, and should facilitate the exchange of filter material (i.e. cartridges), preferably without the need to remove any connections, thus reducing the possibility of leakage. They should be portable for ease of use.

**A.2.3** Facilities should be available to allow for the removal of air from the associated section of the gas cart after the exchange of filter material by means of its internal air-evacuation system (vacuum pump).

**A.2.4** Soda ash Na<sub>2</sub>CO<sub>3</sub> should not be used as a pre-filter material, as it produces CO<sub>2</sub>, which is a stable gas that cannot be removed from the SF<sub>6</sub>. Similarly, a molecular sieve of pore size greater than 4 angstrom should not be used, as thermodynamic reactions might occur under certain conditions, which might cause a burnout or meltdown of the filter interiors.

#### **A.3 Particle filter**

**A.3.1** The particle filter should be placed at the input of a gas reclaimer. It should be capable of holding back particles greater than 1 µm in size, thereby preventing particles from entering mechanical parts of the gas reclaimer or from being discharged into the air through the vacuum pump (or both). It should facilitate the exchange of filter material (i.e. cartridges), preferably without the need to remove any connections, thus reducing the possibility of leakage.

**A.3.2** Facilities should be available to allow for the removal of air from the associated section of the gas cart after the exchange of filter material by means of its internal air-evacuation system (vacuum pump).

#### **A.4 Vacuum pump**

The vacuum pump module is used to extract air from SF<sub>6</sub>-insulated equipment and associated piping prior to refilling with SF<sub>6</sub> and for dehydration (removal of residual moisture). It is also used to remove air from various sections of the gas-processing system itself, for example after maintenance work and after filter exchange. The vacuum pump section should be so designed that accidental backflow of air and oil is prevented. As vacuum pumps are generally oil lubricated, they should not be used for SF<sub>6</sub> processing.



**Annex A***(continued)***A.5 SF<sub>6</sub> vacuum compressor**

**A.5.1** The SF<sub>6</sub> vacuum-compressor module is used to recover SF<sub>6</sub> from gas-insulated equipment and to assist the in-series-connected SF<sub>6</sub> piston compressor to achieve a good level of SF<sub>6</sub> recovery. Its function is to produce a vacuum as low as possible within the electrical equipment and to feed the SF<sub>6</sub> gas to the main compressor.

**A.5.2** The vacuum compressor should be dry running and hermetically sealed to prevent accidental oil or air contamination. It should also have a pneumatic control system that ensures its operation in accordance with the prevailing pressure conditions.

**A.5.3** A piston compressor alone can only achieve a certain pressure differential that would limit the residual recovery pressure depending on the gas pressure in the storage compartment.

NOTE The use of both the abovementioned compressor systems in series will ensure that the desired recovery pressure can be achieved.

**A.5.4** Some systems combine the SF<sub>6</sub> vacuum-compressor module with the vacuum pump. In this case the combination should perform according to requirements for both devices and an automatic shutdown feature should be incorporated to prevent SF<sub>6</sub> from being discharged into the air as a result of operator error.

**A.5.5** Dry-running vacuum pumps have recently become available for SF<sub>6</sub> recovery. As they produce a higher vacuum degree than that produced by vacuum compressors, the costs increase substantially. On the other hand, a higher recovery rate of up to 50 times can be achieved.

NOTE Most vacuum pumps are oil lubricated and produce some oil mist at their exhaust. If vacuum pumps are used for SF<sub>6</sub> processing, the elimination of the oil mist should be ensured. Vacuum pumps are furthermore generally not airtight when a vacuum exists at their discharge side. This is often the case when vacuum compressor and vacuum pump are combined. The use of a vacuum pump in the SF<sub>6</sub> circuit of a gas-processing system should ensure the air tightness between vacuum and compression sections.

**A.6 SF<sub>6</sub> piston compressor**

The piston compressor is used to compress the SF<sub>6</sub> into a storage container. It commonly comprises a single-stage or dual-stage piston compressor. It should be dry running and hermetically sealed to prevent accidental oil or air contamination. Its pressure differential should be sufficient to achieve the maximum storage pressure required to fill the storage container adequately.

**A.7 Gas/moisture filters**

**A.7.1** Filter elements should be adequately sized to remove moisture, gas by-products and particles greater than 1 µm in size (as a second means of trapping larger particles, which might have been transmitted through a non-efficient particle filter). The filter should be a cartridge type and should be capable of being exchanged easily. The desiccant and decomposition filters should be placed between compressor output and storage section. Absorbent filters have better efficiency under higher pressures and elevated temperature.

**A.7.2** Facilities should be provided to allow for the removal of air from the associated section of the gas cart after the exchange of filter material by means of its internal air-evacuation system (vacuum pump).

## Annex A

(continued)

### A.8 SF<sub>6</sub> storage

The SF<sub>6</sub> storage module is used to store SF<sub>6</sub> processed by the reclaimer. It should have sufficient capacity to store the amount of SF<sub>6</sub> to be recovered. It can be an integral part of the gas reclaimer or it can be an external item. If used for liquid storage of SF<sub>6</sub>, it should be rated for at least 70 bar. A net content weighing system should be available in order to determine the degree of filling of the container. If the reclaimer is intended to be transportable when containing gas within its storage containers, it should comply with the local pressure vessel regulations.

### A.9 SF<sub>6</sub> refilling

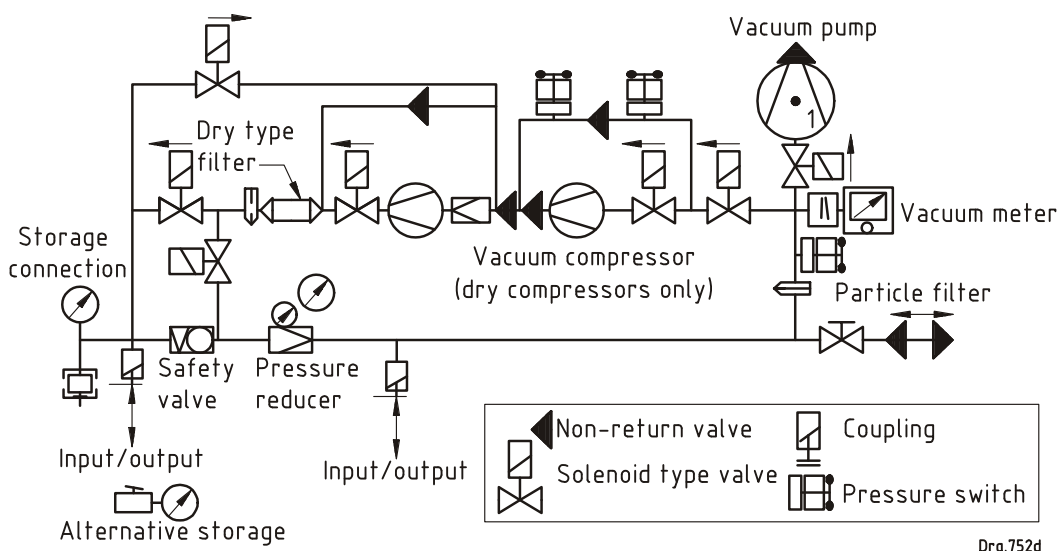
**A.9.1** The SF<sub>6</sub> gas reclaimer should have provisions for refilling of the gas, from the storage vessel, into the electrical equipment. The refilling provisions will vary depending on the storage method. Means should be incorporated to ensure that the electrical equipment is not subjected to overpressure. The SF<sub>6</sub> compressor is generally used to transfer the gas from the storage vessel to the electrical equipment.

**A.9.2** When the gas is stored in gaseous form, it can be refilled by using a regulator and the compressor only.

**A.9.3** When the gas is stored in liquid form, it is necessary to control the temperature of the refilled SF<sub>6</sub> to ensure that freezing cannot occur in the system and that SF<sub>6</sub> is filled into the equipment in vaporized form only.

### A.10 Design example

**A.10.1** Figure A.1 shows the gas flow scheme of a general-purpose SF<sub>6</sub> reclaimer designed for processing normally arced gas.



**Figure A.1 — Typical flow diagram for a general-purpose SF<sub>6</sub> gas reclaimer**

**A.10.2** Each of the various components shown in figure A.1 has specific design considerations in regard to its ability to keep the SF<sub>6</sub> in a reusable state, at acceptable cost, and to prevent accidental gas losses during handling.

## **Annex A**

*(continued)*

**A.10.3** Gas/hose connections should be self sealing to prevent air and moisture from entering the gas-reclaiming equipment. As the equipment will often be left in a state of vacuum or high pressure (or both), these SF<sub>6</sub> valves should be pressure tight and vacuum tight.

**A.10.4** Gas piping and pipe unions used should be of high quality and should preferably use a metal-to-metal reusable sealing system, proven in its performance with SF<sub>6</sub> and its decomposition by-products. They should be

- a) pressure tight and vacuum tight,
- b) vibration proof,
- c) reusable (i.e. indefinite refitting should be possible), and
- d) resistant to temperature change.

**A.10.5** All pipe-work should be of copper tubing silver soldered to tube unions. All components (gauges, valves, filters, etc.) should be securely mounted to the frame of the gas cart in such a way that pipe-work does not have to support them. This prevents stress cracks from causing either gas losses or inadvertent gas mixtures. Heavy components (for example, compressors and vacuum pumps) should be shockproof mounted and should be connected to the fixed pipe-work by means of flexible connections.

**A.10.6** Equipment used to process SF<sub>6</sub> (for example, compressors) should be dry running (oil-less), and of gas-tight construction, and should not contain any internal components that can corrode by being exposed to decomposition by-products (for example galvanized metal).

**A.10.7** Solenoid type valves that close automatically in the case of a loss of power should be used to control the gas flow.

**A.10.8** Vacuum pumps used to extract air and moisture from electric power equipment or gas-reclaiming equipment should have an oil backflow prevention valve. Storage tanks should not be internally coated.

**A.10.9** SF<sub>6</sub> compressors should be protected against pressure and temperature, and should be able to shut off solenoid type valves in the case of overload or failure.

**A.10.10** Filter elements should be as described in A.7.

## **A.11 Safety features**

Operator safety features, especially systems to prevent operator errors, should be incorporated into gas reclaimers. The following features will assist in achieving safe operation:

- a) pressure relief valves at all critical sections;
- b) automatic control of gas temperature;
- c) check valves at critical points throughout the gas reclaimer; and
- d) appropriate wiring, screening of live components and grounding of all electrical equipment.

**Annex A**  
(concluded)**A.12 Ability to maintain original gas quality**

Important design features to ensure the conservation of gas quality include the following:

- a) vacuum pump oil backflow prevention;
- b) dry-running (oil-less) SF<sub>6</sub> processing components;
- c) use of high reliability tubing and fittings;
- d) gas-tight compressor designs;
- e) self-sealing pressure/vacuum connections with minimum flow restriction; and
- f) vibration-proof mounting of components.

**A.13 Transportability**

Transportability is an essential feature for many applications. For small gas volumes, assemblies that can be transported in a car or small van and set up on site might suffice. For large gas volumes, a trailer-mounted self-contained assembly is required. Special care should be taken to ensure that the storage vessel used can be transported legally when filled with SF<sub>6</sub>.

## Annex B (informative)

### On-site SF<sub>6</sub> gas-reclaiming recommendations

#### B.1 General

On-site gas-reclaiming procedures are based on the absorption of impurities. Operational contamination should already have been absorbed by the user's filter unit. Such filters are an integral part of the company's SF<sub>6</sub> maintenance devices, or are available as separate filter units.

#### B.2 Filtering recommendations

The filters should comply with the following recommendations:

- a) filters should reliably remove the mentioned contaminants;
- b) filters should be of the cartridge type for safe and easy disposal;
- c) input and output should be equipped with the same self-sealing couplings;
- d) changing filters should not require dismantling of any fittings, tubing, or any other connection to eliminate the possibility of leakage; and
- e) the filter should be changed for each purification operation.

#### B.3 Reclaiming methods

Requirements for the quality of reclaimed SF<sub>6</sub> are given in this specification. All occurring contaminants are formed during normal operation and can be eliminated on site. Table B.1 lists the type of contamination and the methods recommended for removing the impurities.

**Table B.1 — Suggested reclaiming operations**

1	2
Operational contamination	Reclaiming method
Moisture (water vapour)	Adsorption with molecular sieve
Gaseous decomposition by-products	Adsorption with activated aluminium oxide
Solid decomposition by-products	Retaining with solid filters
SF <sub>6</sub> mixed with other gases (air or CF <sub>4</sub> )	SF <sub>6</sub> gas separation device
Contamination with mineral oil	Activated charcoal filter

**Annex B***(concluded)*

Various types of adsorbent materials are available to remove contaminants from SF<sub>6</sub> gas (see table B.2).

**Table B.2 — Typical adsorbents for various SF<sub>6</sub> impurities**

1	2
<b>Adsorbent</b>	<b>Contaminants removed</b>
Molecular sieve 4A	Water, SO <sub>2</sub> , SOF <sub>2</sub> , SF <sub>4</sub>
Molecular sieve 13X	Water, SO <sub>2</sub> , SOF <sub>2</sub> , SF <sub>4</sub> (also adsorbs some SF <sub>6</sub> )
Activated aluminium oxide	Water, SO <sub>2</sub> , SOF <sub>2</sub> , SF <sub>4</sub> , HF
Soda lime (Ca(OH) <sub>2</sub> + NaOH)	Water, SO <sub>2</sub> F <sub>2</sub> , HF
Activated charcoal	Oil vapour

Through the corresponding handling with service devices, the gas will be purified and finally verified. If the salvaged material meets the requirements for unreserved reuse in electrical installations, direct refilling with a filling-and-evacuating device will be required. This handling covers the normal operation of electrical equipment.

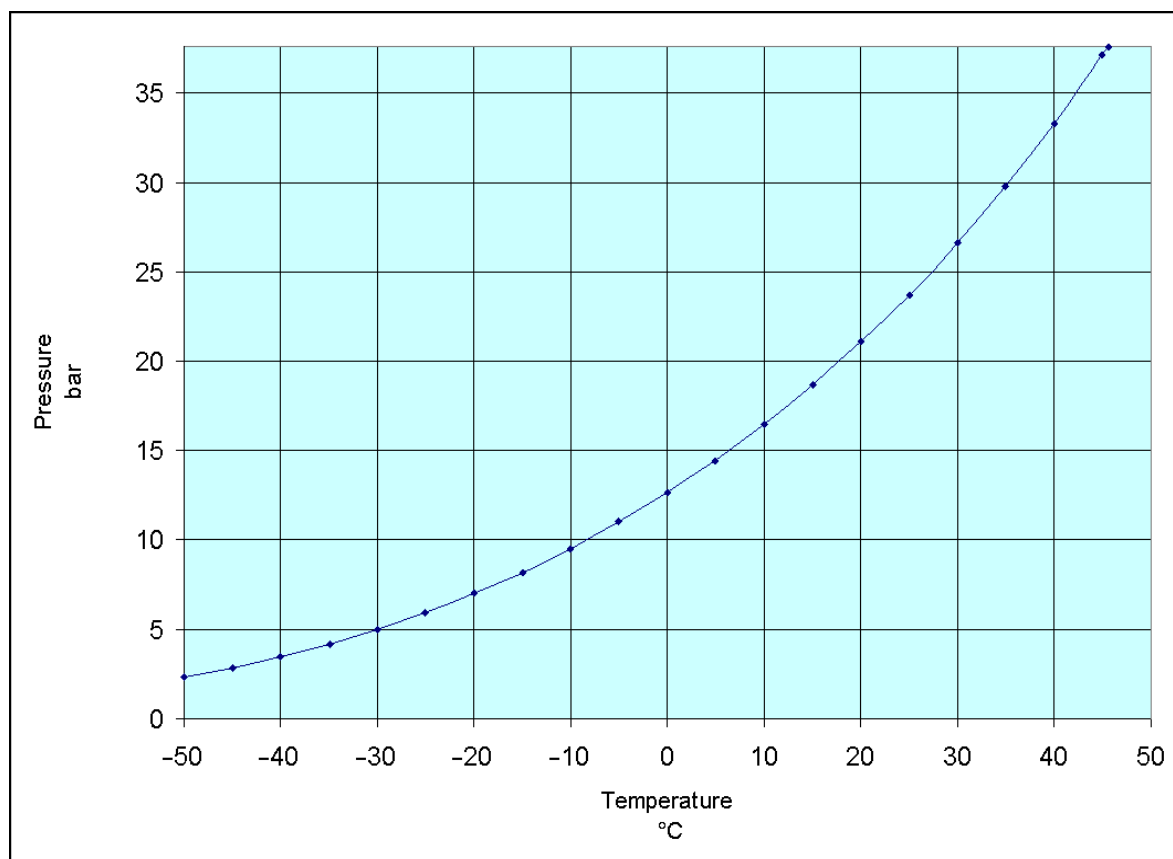
If, when tested, the gas shows a level of decay that is unacceptable in terms of the requirements of this specification, a decision regarding the reclaiming method should be made depending on the level and type of contamination. In general, repurifying the gas on site with a service device plus a separation device will be the most favourable method. However, if reuse is not possible, disposal will be necessary. In this case, the gas should be sent to the SF<sub>6</sub> manufacturer or reclaimer.

### Annex C

(informative)

#### **SF<sub>6</sub> vapour pressure curve**

Figure C.1 shows a vapour pressure curve.



**Figure C.1 — SF<sub>6</sub> vapour pressure curve**

**Annex D**

(informative)

**Example of a typical SF<sub>6</sub> reporting form**

Name:	Company name:
Title:	Month or year:
Phone:	Date completed:

**Change in inventory (SF<sub>6</sub> contained in cylinders, not electrical equipment)**

Inventory (in cylinders, not equipment)	Amount kg	Comments
1. Beginning of year		
2. End of year		
<b>A. Change in inventory (1 - 2)</b>		

**Purchases/acquisitions of SF<sub>6</sub>**

Purchases/acquisitions	Amount kg	Comments
3. SF <sub>6</sub> purchased from producers or distributors in cylinders		
4. SF <sub>6</sub> provided by equipment manufacturers with/inside equipment		
5. SF <sub>6</sub> returned to the site after off-site recycling		
<b>B. Total purchases/acquisitions (3 + 4 + 5)</b>		

**Sales/disbursements of SF<sub>6</sub>**

Sales/disbursements	Amount kg	Comments
6. Sales of SF <sub>6</sub> to other entities, including gas left in equipment that is sold		
7. Returns of SF <sub>6</sub> to supplier		
8. SF <sub>6</sub> sent to other facilities		
9. SF <sub>6</sub> sent off site for recycling		
<b>C. Total sales/disbursements (6 + 7 + 8 + 9)</b>		

**Change in nameplate capacity**

Change in nameplate capacity	Amount kg	Comments
10. Total nameplate capacity (proper full charge) of new equipment		
11. Total nameplate capacity (proper full charge) of retired or sold equipment		
<b>D. Change in capacity (10 - 11)</b>		

Total annual emissions	SF <sub>6</sub> kg	Tonnes CO <sub>2</sub> equiv. (kg SF <sub>6</sub> × 23,900/1000)
<b>E. A + B - C - D</b>		



## **Annex E** (informative)

### **SF<sub>6</sub> quality checking instruments**

#### **E.1 Equipment**

##### **E.1.1 Moisture**

Many different physical quantities and related measurement units are used to give the moisture contained in a gas. They include mass concentration expressed in micrograms per gram ( $\mu\text{g/g}$ ), dew point expressed in degrees Celsius ( $^{\circ}\text{C}$ ), relative moisture expressed as a percentage (normally not used) and absolute moisture expressed in grams per cubic centimetre ( $\text{g/cm}^3$ ). Conversion among these units is provided in IEEE 1125. The volume concentration in microlitres per litre ( $\mu\text{L/L}$ ) is suggested as the reference unit for future documents on electric power equipment.

The concentrations are the only figures expressing the moisture content that do not vary when the gas pressure is changed. Thus when the moisture content is measured in SF<sub>6</sub> - insulated equipment, if volume ( $\mu\text{L/L}$ ) or mass ( $\mu\text{g/g}$ ) concentrations are used, the value remains constant. This is also true in the case of the actual pressure of the gas changes due to modifications of the ambient temperature (for example summer or winter (or both)). Hence the moisture content, measured as a concentration expressed either in microlitres per litre or micrograms per gram, needs no reference pressure (i.e. the pressure at which the measurement was performed).

The following measurement principles for moisture are currently used:

- a) physical dew-point meters;
- b) electronic dew-point meters; and
- c) chemical reaction tubes with visual indication.

##### **E.1.2 Physical dew-point meters**

Chilled mirror type instruments allow the sample gas to be passed onto a reflective part that is cooled during the measuring process. A light-sensitive system is activated by the reflection from the mirror. Once the dew-point temperature has been reached, moisture fogs up the reflective mirror and the light-sensitive device picks up the difference in reflection. The temperature is recorded when this occurs, and the dew point is then known. These instruments are commercially available; they tend to be more expensive, but are more accurate, than other available dew-point meters. They are, however, vulnerable to particle or corrosive gas damage (or both).

Other physical types of dew-point meters allow the user to watch a reflective mirror until fog can be seen to build up whilst the mirror is cooled down. These devices are commercially available. They typically require an external source for cooling material (i.e. dry ice), and use more gas than comparable electronic systems, and the results are subjective because they depend on the user's skill and knowledge.

##### **E.1.3 Electronic dew-point meters**

This category refers to devices that use an electronic sensor to detect the dew point of the sample gas. Ceramic sensors and aluminium oxide sensors change capacitance with very small changes in water vapour. Changes in capacitance are converted to indicate the moisture content of the gas. These capacitance-sensor-based instruments are the most widely used types of moisture measurement instruments for SF<sub>6</sub>. They are available from a wide range of manufacturers.

**Annex E***(continued)*

The following is a list of features that are important in the selection of a suitable type:

- a) response time;
- b) gas release;
- c) corrosion resistance;
- d) life time of sensor;
- e) calibration; and
- f) price.

Other types that would probably belong to this category are the electrolytic type instruments which measure the moisture content in the gas sample with a phosphorous pentoxide film coated between two platinum electrodes in the electrolytic cell. The water vapour is dissociated into hydrogen and oxygen when direct current is applied, the amount of current used to dissociate the water being converted to a direct moisture content reading in microlitres per litre ( $\mu\text{L/L}$ ) (ppmv).

Most recent dew-point meters display the dew point at atmospheric pressure as well as at the operating pressure in the power equipment.

**E.1.4 Chemical reaction tubes with visual indication**

The refrigeration industry uses a wide range of so-called eyeglass dew-point indicators. These dew-point indicators use a chemically reactive material that changes its colour at a certain dew point. The observer gets a general indication if the gas is dry or wet. Past trials of this technology with  $\text{SF}_6$  gas have not been very positive as these indicators are pressure sensitive, and readings vary with pressure.

**E.1.5 Summary of desirable features of dew-point meters**

The following list summarizes the desirable features of dew-point meters:

- a) measuring range 10  $\mu\text{L/L}$  (10 ppmv) to at least 500  $\mu\text{L/L}$  (500 ppmv);
- b) accuracy of  $\pm 20 \mu\text{L/L}$  (20 ppmv);
- c) sensor resistance to oil traces and corrosive gases;
- d) portable permeation-resistant connecting pipes using self-sealing valve connections;
- e) calibrated or field calibratable;
- f)  $\text{SF}_6$  gas release of less than 1 bar per litre ( $\sim 6 \text{ g}$ ) per measurement; and
- g) average time to obtain result less than 5 min.

**E.2 Reactive gases ( $\text{SF}_6$  decomposition by-products)**

Reactive gaseous  $\text{SF}_6$  decomposition by-products include various gaseous fluorides such as  $\text{SF}_4$  and  $\text{WF}_6$ , oxifluorides like  $\text{SOF}_2$ ,  $\text{SOF}_4$ , and  $\text{SO}_2\text{F}_2$ , the oxide  $\text{SO}_2$ , and hydrogen fluoride HF. All of these gases could principally be detected using gas chromatography or infrared spectrometers. However, low-cost measurement devices are only available for  $\text{SO}_2$  and HF. Devices for  $\text{SO}_2$  are also found to be sensitive to  $\text{SOF}_2$ . The devices for HF are less sensitive than those for  $\text{SO}_2$ .

## Annex E

(concluded)

Because of the difficulty of measuring all reactive gases, it is recommended that one or two of them be selected as indicators for the total concentration of all reactive gases. The gases  $\text{SO}_2$  and  $\text{SOF}_2$  are particularly suitable because they make up a major fraction of all reactive contaminants, which might remain in reclaimed gas after filtering. Their relative abundance is determined by the stoichiometry of the reactions by which they are created and is approximately  $(\text{SO}_2 + \text{SOF}_2) / \text{HF} = 1:2$  to  $1:4$ , i.e.  $1:3$  on average. Therefore, if the sum concentration of  $\text{SO}_2 + \text{SOF}_2$  is measured, the total concentration, including HF, is about three to four times higher, for example a reading of  $12 \mu\text{L/L}$  ( $12 \text{ ppmv}$ ) would indicate a total concentration of  $\text{SO}_2$ ,  $\text{SOF}_2$  and HF of about  $50 \mu\text{L/L}$  ( $50 \text{ ppmv}$ ). In order to account for this indicator function of  $\text{SO}_2 + \text{SOF}_2$ , an equivalent level has been included in the purity requirements.

The current technology to detect  $\text{SO}_2$  by a portable field instrument is to use so-called detector tubes, which change their initial colour if  $\text{SF}_6$ -containing  $\text{SO}_2$  or  $\text{SOF}_2$  is fed through them. The device samples a small amount of  $\text{SF}_6$  from the equipment ( $0,5 \text{ L}$  at  $2 \text{ bar}$ ). This sample gas is then released through the test tube, thus a quantitative measurement is possible. Typical measuring range is  $0 \mu\text{L/L}$  ( $0 \text{ ppmv}$ ) to  $20 \mu\text{L/L}$  ( $20 \text{ ppmv}$ ).

Electronic and electrochemical  $\text{SO}_2$  sensors have been developed but have not yet been tested in  $\text{SF}_6$ -insulated power technology. Desirable features include the following:

- a) measuring range up to  $20 \mu\text{L/L}$  ( $20 \text{ ppmv}$ );
- b) calibration for  $\text{SO}_2$  and  $\text{SOF}_2$ ;
- c) accuracy of  $\pm 10 \%$ ;
- d) portable decomposition-by-product-resistant connecting pipes using self-sealing valve connections; and
- e)  $\text{SF}_6$  gas release of less than  $1 \text{ bar}$  per litre ( $\sim 6 \text{ g}$ ) per measurement.

### E.3 Non-reactive gases (air and $\text{CF}_4$ )

These include mostly air (introduced by handling) and  $\text{CF}_4$  (produced by arc erosion of polymers). Devices that compare the speed of sound or the thermal conductivity of the  $\text{SF}_6$  gas mixture with pure  $\text{SF}_6$  can measure the concentrations of these gases. Speed-of-sound-based systems are fast (response time less than  $1 \text{ min}$ ) and accurate to  $\pm 1 \%$ . They do not need recalibration and use only a minimal amount of gas. Their readout is the  $\text{SF}_6$  concentration as a percentage of the volume. They are mostly calibrated for mixtures of  $\text{SF}_6$  and nitrogen or air (or both), but can also be calibrated for  $\text{SF}_6$  and  $\text{CF}_4$  mixtures. Devices (such as oxygen sensors) that measure the concentration of the non-reactive gases and then calculate the percentage of  $\text{SF}_6$  should not be used, as different non-reactive gases such as nitrogen ( $\text{N}_2$ ) or  $\text{CF}_4$  might be present.

Desirable features include the following:

- a) accuracy better than  $\pm 1 \%$  of the volume;
- b) response time  $< 1 \text{ min}$ ;
- c) no recalibration required;
- d) separate portable calibration for air and  $\text{CF}_4$  mixtures with  $\text{SF}_6$ ; and
- e)  $\text{SF}_6$  gas release of less than  $0,5 \text{ bar}$  per litre ( $\sim 3 \text{ g}$ ) per measurement.

## **Annex F**

(normative)

### **Disposal of solid decomposition by-products**

#### **F.1 Waste disposal and decontamination preparation**

**F.1.1** Use two rubbish bins and lids labelled: "Waste Disposal" and "Recycle" respectively. Check to ensure that they do not have holes or leaks.

**F.1.2** Line each bin with three heavy-duty refuse type plastics bags, one inside the other, tops over the rim of the bin so that the bottoms of the bags rest on the base of the bin.

**F.1.3** Pour 20 L of water into each bin. Add 250 g (1 cup) of calcium chloride to the water in each bin (for sodium bicarbonate, use 500 g per 5 L of water).

**F.1.4** Leave standing for at least one (1) hour with the lids on before putting in waste or clothing.

#### **F.2 Waste disposal procedure (dust from the high efficiency particulate air vacuum cleaner)**

**F.2.1** Using the full personal protective clothing kit as specified, open the base of the vacuum cleaner to expose the paper bag.

**F.2.2** Carefully ease the paper bag off its fitting in the vacuum cleaner, take care not to "snap" the rubber seal which holds the paper bag to the fitting. This could release some of the SF<sub>6</sub> by-product or decomposition by-product.

**F.2.3** Place the paper bag (base first) in the "Waste Disposal" bin. Hold the bag at its top. The bag should start dissolving when it comes into contact with the water/calcium chloride mixture in the bin.

**F.2.4** Release the bag, put the bin lid back on, and gently shake the bin so that the paper bag becomes thoroughly immersed. Leave to soak for 24 h.

#### **F.3 Final disposal**

**F.3.1** Although the chemical substances in SF<sub>6</sub> are highly toxic both in its by-product stage (inside the system) and in its decomposition by-product stage (released outside the system), they are rendered less toxic by the use of a chemical neutralizer, such as sodium bicarbonate.

**F.3.2** For the disposal of the waste, contact the local risk officer for advice on the final disposal in terms of waste site, procedure, etc. The disposal of all waste shall be in compliance with the requirements of environment conservation legislation (see foreword). There are specific sites allocated for the disposal of different classes of waste.

**F.3.3** All disposal shall be undertaken in conjunction with national legislation (see foreword). Owners of hazardous waste shall be responsible for the safe disposal thereof.

**F.3.4** SF<sub>6</sub> waste shall only be treated or disposed of (or both) by facilities licensed by the relevant authority (see foreword) and through processes that minimize the release of waste into the environment. The disposal facility shall supply proof of a valid licence to the waste owner for record-keeping purposes.

**Annex F**  
(concluded)

**F.3.5** When SF<sub>6</sub> gas or equipment containing SF<sub>6</sub> gas is returned to the manufacturer or sent for disposal, the manufacturer or disposal facility operator shall supply the owner with information pertaining to its safe management after return to the manufacturer or with a safe-disposal certificate in the case of a disposal facility. This is to ensure the waste owner's "duty of care". The safe-disposal certificate shall indicate the name of the waste owner, the quantity of SF<sub>6</sub> destroyed, the date of destruction, and the disposal facility's name and licence number. A register of completed safe-disposal certificates shall be kept and maintained by the waste owner. Disposal records shall be retained for a minimum period of five years.

## Annex G

(normative)

### Sampling methods

#### G.1 General

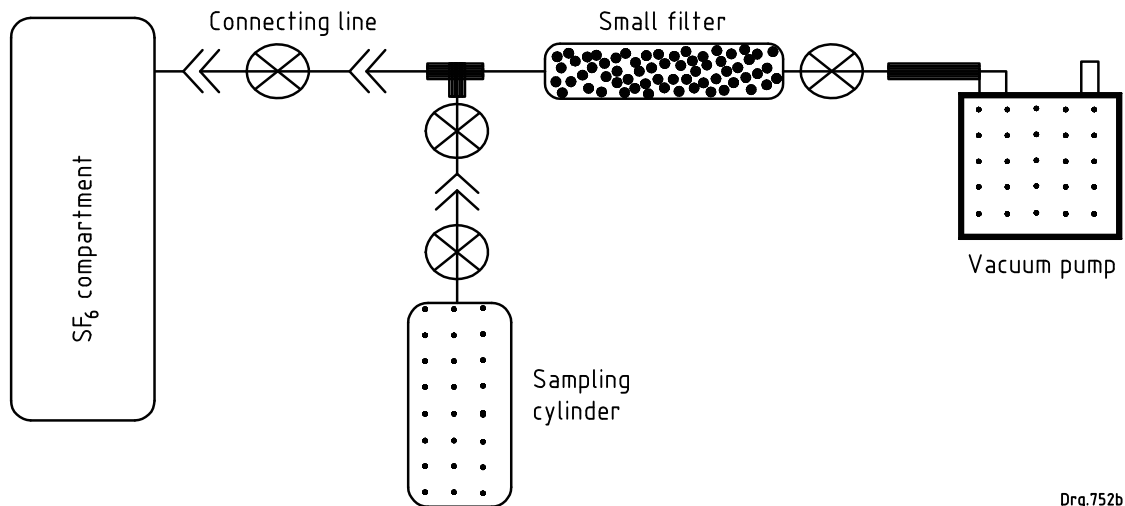
A sample shall be representative of the gas composition in a reservoir. The sample shall be taken from the liquid phase. If there is no liquid  $\text{SF}_6$  in the reservoir, the gas sample will be truly representative of the gas.

Before a sample is taken from the reservoir, the volumetric contents of all the connections from the reservoir to the analytical equipment or sample cylinder shall be evacuated with a vacuum pump. On the reservoir, if the sampling port is connected to the main chamber by a long section of narrow pipe, the pipe connection shall be purged, with gas from the reservoir, to ensure that the sample is representative of the  $\text{SF}_6$  in the reservoir.

As far as possible, the components in contact with the  $\text{SF}_6$  shall be constructed of stainless steel or other chemically resistant material to minimize reactions and contamination during the sampling process. The sample to be analysed shall not pass through an active filter (molecular sieve, aluminium oxide) that could alter the gas composition. However, a particle filter might be necessary to ensure that the sample is not contaminated with particles.

To minimize the release of  $\text{SF}_6$  into the atmosphere and to limit the exposure of personnel to toxic decomposition by-products, a collecting bag or similar equipment shall be used (see figures G.1 and G.2). The gas in the collecting bag shall be reclaimed.

These figures serve to illustrate the field sampling procedure.



Drg.752b

**Figure G.1 —  $\text{SF}_6$  gas-sampling set-up for evacuation**

## Annex G (concluded)

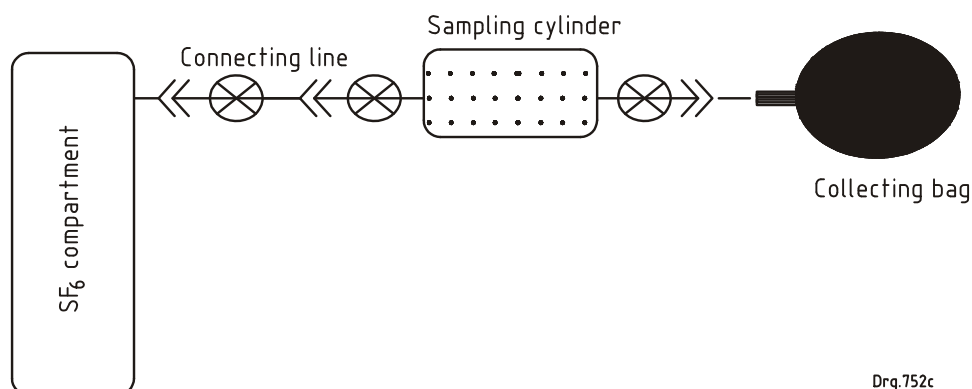


Figure G.2 — SF<sub>6</sub> gas-sampling set-up for purging

### G.2 On-site sampling connection

A direct connection is required for all on-site methods of analysis. The connecting line should be stainless steel tubing of nominal outer diameter 3 mm to 6 mm, and of length not exceeding 2 m. The ends of the line should have self-sealing fittings or valves to seal the line from ambient air contamination when not in use.

### G.3 Sampling for laboratory analysis

The cylinder volume shall be in the range of 150 mL to 500 mL (a larger volume, up to 1 000 mL, might be needed for the Fourier transformed infrared analysis). All materials of the cylinder and valve in contact with the sample shall be stainless steel or chemically resistant materials, such as polytetrafluoro-ethylene. The cylinder and connections need to operate at high pressure (5 MPa).

The following procedure is recommended in order to remove any impurity (see figure G.1):

- a) heat the cylinder to 100 °C and evacuate for 1 h (primary vacuum);
- b) close the valve and cool the cylinder completely to room temperature before using;
- c) flush with dry N<sub>2</sub> and evacuate the gas; and
- d) repeat the operation and keep the cylinder evacuated.

Connect the cylinder to the sampling port of the reservoir as for a direct connection. Fill the cylinder once and wait 1 min to allow the conditioning of the inside wall, then evacuate and fill it again. After filling the cylinder with the sample, plug the valve opening to ensure that the sample is not lost owing to inadvertent opening of the valve during transport to the laboratory. A self-sealing fitting is suitable for a plug and facilitates all aspects of sample handling.

In the case of purging (see figure G.2), a collecting bag or similar equipment should be used in order to avoid any release of SF<sub>6</sub>. A few litres of SF<sub>6</sub> can then be passed through the cylinder to condition its internal walls. After analysis, SF<sub>6</sub> samples should be reclaimed.

**Annex H**

(normative)

**Requirements for the use of a respirator and protective clothing****H.1 Respirator**

Guidance regarding the assembly and fitting of the respirator shall be obtained from the manufacturer's instructions supplied with the equipment. It is important to realize that the respirator mask shall achieve a good face seal in order to be effective. Its effectiveness could be affected by the presence of a beard or facial hair.

The respirator and canister will filter out toxic gas and dust but it is not suitable when the atmosphere is deficient in oxygen. If there is a possibility of an oxygen deficiency, an oxygen-deficiency meter shall be used to establish whether such a hazard exists. The respirator and the protective clothing shall be worn when equipment is being opened for maintenance or during an emergency when personnel might come into contact with the gas or associated decomposition by-products. This also applies to the changing of gas filters on circuit-breakers or gas-servicing equipment generally.

The respirator canister shall be changed after a period of 30 minutes' use when the wearer is exposed to SF<sub>6</sub> gas decomposition by-products, and whenever the face mask is worn by another person. Cleaning of the face mask and breathing tube shall be carried out using soap and water, and they may be wiped with a mild solution of disinfectant if required. After use, the canister shall be removed and disposed of, but a new one shall not be fitted until required. Ensure that the shelf life has not expired. When maintenance which involves opening of the SF<sub>6</sub>-filled equipment is carried out, all preliminary work which does not require the use of the respirator (including removal of the gas and preparation for opening) shall be completed before the respirator is worn. This will enable the best use to be made of the canister exposure duration, which is 30 minutes.

**H.2 Protective clothing**

Disposable overalls shall have elasticized wrist and ankle fastenings, and shall be fitted with hoods. These overalls are one size and can be worn over the normal overalls. The disposable overalls retain body heat, owing to the restricted breathing of the material, and this should be borne in mind by personnel when dressing.

Normal clothing that has been removed shall be stored away from contamination in the washing and changing area designated for use during SF<sub>6</sub> working. The disposable overalls shall be worn with the elasticized wrist and ankle fastenings over the gloves and boots to prevent any dust from entering at these points. The hood shall be fitted after the respirator has been donned. A safety helmet can be worn over the hood when necessary.

On completion of work involving use of the protective clothing, including the full face respirator, personnel shall clean themselves with disposable cleaning materials before removing their respirators. The overalls shall be removed before the boots and gloves and shall be dealt with in accordance with 7.2.5. After removing their boots and gloves, personnel shall wash their hands and faces thoroughly before dressing in their normal clothes.



## Annex I

(informative)

### Example of a material safety data sheet for SF<sub>6</sub>

#### I.1 Product identification

Product name: Sulfur hexafluoride  
Chemical formula: SF<sub>6</sub>  
Product use description: For general analytical or synthetic chemical uses

#### Composition of, and information on, ingredients

Components	CAS Number	Concentration (volume)
Sulfur hexafluoride	2551-62-4	100 %

#### I.2 Hazards identification

Sulfur hexafluoride is a colourless, odourless, non-toxic, non-flammable gas which is shipped as a liquefied gas. The liquefied gas will rapidly boil at standard temperatures and pressures. The main health hazard associated with releases of this gas is asphyxiation, by displacement of oxygen. Contact with the liquefied gas can cause frostbite to any contaminated tissue. Sulfur hexafluoride is not flammable or reactive under typical emergency response situations.

#### I.3 Emergency overview

Can cause rapid suffocation.

Compressed liquefied gas.

Avoid inhaling gas.

Direct contact with liquid can cause frostbite.

Self-contained breathing apparatus (SCBA) might be required.

#### Potential health effects

Inhalation:	Inhalation of high concentrations might also cause mild central nervous system depression and heartbeat irregularities. In high concentrations, inhalation might cause asphyxiation. Symptoms could include loss of mobility or loss of consciousness. Victim might not be aware of asphyxiation. Asphyxiation could lead to unconsciousness without warning so rapidly that the victim might be unable to protect himself/herself.
Eye contact:	Contact with liquid might cause cold burns or frostbite.
Skin contact:	Contact with liquid might cause cold burns or frostbite.
Ingestion:	Ingestion is not considered a potential route of exposure.
Chronic health hazard:	Not applicable.

## **Annex I**

*(continued)*

### **Exposure guidelines**

Primary routes of entry:	Inhalation.
Target organs:	None.
Symptoms:	Exposure to an oxygen-deficient atmosphere might cause the following symptoms: dizziness, salivation, nausea, vomiting, and loss of mobility or consciousness

### **Aggravated medical condition**

None known.

### **I.4 First-aid measures**

General advice:	While wearing SCBA, remove the victim to an uncontaminated area. Keep the victim warm and rested. Call a doctor. Apply artificial respiration if breathing has stopped.
Eye contact:	In the case of contact with eyes, rinse immediately with plenty of clean, cold water and seek medical advice. Keep eyes wide open while rinsing.
Skin contact:	Wash frostbitten areas with plenty of clean, cold water. Do not remove clothing. Cover the wound with a sterile dressing.
Ingestion:	Ingestion is not considered a potential route of exposure.
Inhalation:	Move the victim to an area with fresh air. If breathing has stopped or is laboured, give assisted respiration. Supplemental oxygen might be indicated. If the heart has stopped, trained personnel should begin cardiopulmonary resuscitation immediately. In the case of shortness of breath, give the victim oxygen.

### **I.5 Fire-fighting measures**

Suitable extinguishing media:	All known extinguishing media can be used.
Specific hazards:	Exposure to high temperatures might yield toxic by-products which could be corrosive in the presence of moisture. Upon exposure to intense heat or flame, the cylinder will vent rapidly or rupture violently (or both). The product is non-flammable and does not support combustion. Move away from the cylinder and cool with water from a protected position. If possible, stop the flow of product. Keep adjacent cylinders cool by spraying with large amounts of water until the fire burns itself out. Most cylinders are designed to vent contents when exposed to elevated temperatures.
Special protective equipment:	Wear SCBA designed for fire fighting if necessary.

## **Annex I**

*(continued)*

### **I.6 Accidental release measures**

Personal precautions:	Evacuate personnel to safe areas. Wear SCBA when entering the area unless the atmosphere is proved to be safe. Ventilate the area. Monitor the oxygen level.
Environmental precautions:	SF <sub>6</sub> should not be released into the environment. Do not discharge it into any place where its accumulation could be dangerous. Prevent further leakage or spillage. Prevent SF <sub>6</sub> from entering sewers, basements or workpits, or any other place where its accumulation could be dangerous.
Methods for cleaning up:	Ventilate the area.
Additional advice:	If possible, stop the flow of product. Increase ventilation to the affected area and monitor the oxygen level. If the leak is from a cylinder or cylinder valve, contact the SF <sub>6</sub> gas supplier. If the leak is in the user's system, close the cylinder valve, safely vent the pressure, and purge with an inert gas before attempting repairs.

### **I.7 Handling, and storage and technical measures/precautions**

#### **I.7.1 Handling**

Only experienced and properly instructed persons should handle compressed gases. Protect cylinders from physical damage; do not drag, roll, slide or drop. Do not allow the storage area temperature to exceed 50 °C (122 °F). Before using the product, determine its identity by reading the label. Know and understand the properties and hazards of the product before using it. When there is uncertainty about the correct handling procedure for a particular gas, contact the supplier. Do not remove or deface the labels provided by the supplier for the identification of the cylinder contents. When moving cylinders, even for short distances, use a cart, trolley or similar mobile unit designed to transport cylinders. Leave valve protection caps in place until the cylinder has been secured against either a wall or a bench, or has been placed in a container stand, and is ready for use. Use an adjustable strap wrench to remove overtight or rusted caps.

Before connecting the cylinder, check to ensure that the complete gas system is suitable and compatible, particularly with regard to pressure rating and materials of construction. Also ensure that backflow from the system into the cylinder is prevented. Ensure that the complete gas system has been checked for leaks before use. Employ suitable pressure-regulating devices on all cylinders when emitting the gas to systems with a lower pressure rating than that of the cylinder. Never insert an object (such as a wrench, screwdriver, or pry bar) into a valve cap opening. Doing so might damage the valve, causing a leak to occur.

Open the valve slowly. If the user experiences any difficulty operating the cylinder valve, (s)he should discontinue use and contact the supplier. Close the cylinder valve after each use, even when the cylinder is empty and still connected to equipment. Never attempt to repair or modify cylinder valves or safety relief devices. Damaged valves should be reported to the supplier immediately. Replace outlet caps or plugs and cylinder caps as soon as the cylinder is disconnected from equipment.

Do not subject a cylinder to abnormal mechanical shocks which might cause damage to its valves or safety devices. Never attempt to lift a cylinder by its valve protection cap or guard. Always use a backflow protective device in piping. When returning the cylinder, install a valve outlet cap or plug the leak tight. Never use direct flame or electrical heating devices to raise the pressure of a cylinder. Cylinders should not be subjected to temperatures above 50 °C (122 °F). Prolonged periods of cold temperatures below -30 °C (20 °F) should be avoided. Never attempt to increase the liquid withdrawal rate by pressurizing the cylinder without first consulting the supplier. Never permit liquefied gas to become trapped in parts of the system, as this might result in hydraulic rupture.

## **Annex I**

*(continued)*

### **I.7.2 Storage and technical measures/precautions**

Full cylinders should be stored so that the oldest stock is used first. Cylinders should be stored in the vertical position and should be properly secured to prevent toppling. The cylinder valves should be tightly closed and, where appropriate, valve outlets should be capped or plugged. Cylinder valve guards or caps should be in place. Observe all regulations and local requirements regarding the storage of cylinders (see SANS 10263-2). Stored cylinders should periodically be checked for general condition and leakage. Protect cylinders stored in the open against rusting and extremes of weather.

Cylinders should not be stored in conditions likely to promote corrosion. They should be tightly closed and should be stored in a purpose-built compound, which should be cool and well ventilated, preferably in the open air. Store cylinders in a location that is free from fire risk, away from sources of heat and ignition and away from other combustible materials. Full and empty cylinders should be stored separately. Do not allow the storage temperature to exceed 50 °C (122 °F). Return empty cylinders timeously.

Cylinders should be separated in the storage area according to the various categories (e.g. flammable, toxic, etc.).

### **I.8 Exposure controls/personal protection engineering measures**

Provide natural or mechanical ventilation to prevent oxygen-deficient atmospheres below 19,5 % oxygen. Exposure limits of SF<sub>6</sub> are given in table I.1.

#### **Personal protective equipment**

Respiratory protection:	SCBA or positive pressure airline with mask should be used in an oxygen-deficient atmosphere. Air-purifying respirators will not provide protection. Users of breathing apparatus should be trained.
Hand protection:	Sturdy work gloves are recommended for handling cylinders. The breakthrough time of the selected glove(s) shall be greater than the intended use period.
Eye protection:	Safety glasses are recommended when cylinders are handled.
Skin and body protection:	Safety shoes are recommended when cylinders are handled.
Special instructions:	Ensure adequate ventilation, especially in confined spaces.

## Annex I

(continued)

Table I.1 — Exposure limits of SF<sub>6</sub>

1	2	3
International exposure limits	µg/g (ppmw)	mg/m <sup>3</sup>
Time-weighted average (TWA): ACGIH <sup>a</sup>	1,000 µg/g <sup>b</sup>	6,000 mg/m <sup>3</sup>
Recommended exposure limit (REL): NIOSH <sup>c</sup>	1,000 µg/g <sup>b</sup>	6,000 mg/m <sup>3</sup>
Permissible exposure limit (PEL): OSHA Z1 <sup>d</sup>	1,000 µg/g <sup>b</sup>	6,000 mg/m <sup>3</sup>
Time-weighted Average (TWA) Permissible Exposure Limit (PEL): US CA OEL <sup>e</sup>	1,000 µg/g <sup>b</sup>	6,000 mg/m <sup>3</sup>
a ACGIH – American Conference of Governmental Industrial Hygienists. b Average value of exposure during the course of an eight-hour work shift. c NIOSH – National Institute for Occupational Safety and Health. d US Occupational Safety and Health Administration. Table Z.1 – Limits for air contaminants. e US CA OEL – United States California occupational exposure limit.		

### I.9 Physical and chemical properties of SF<sub>6</sub>

Form:	Liquefied gas.
Colour:	Colourless gas.
Odour:	No odour warning properties.
Molecular weight:	146,05 g/mol
Relative density, gas (air = 1):	5
Relative density, liquid (water = 1):	1,4
Vapour pressure:	21,00 bar at 20 °C
Density:	0,0061 g/cm <sup>3</sup> at 21 °C
Specific volume:	0,1636 m <sup>3</sup> /kg at 21 °C
Boiling point/range:	– 64 °C
Critical temperature:	45,5 °C
Melting point/range:	– 50,8 °C
Water solubility:	0,041 g/L

### I.10 Stability and reactivity

Stability:	Stable under normal conditions.
Conditions to avoid:	Alkali and alkaline earth metals – powdered aluminum, zinc.
Hazardous reactions:	Thermal decomposition yields toxic by-products that can be corrosive in the presence of moisture.

**Annex I**  
(continued)**I.11 Toxicological information (health hazards)**

Ingestion:	No available data on the product itself.
Inhalation:	No available data on the product itself.
Skin:	No available data on the product itself.

**I.12 Ecological information and ecotoxicological effects**

This product has no known ecotoxicological effects.

Aquatic toxicity:	No available data on the product itself.
Toxicity to other organisms:	No available data.
Mobility:	No available data.
Bioaccumulation:	No available data on the product itself.

**I.13 Disposal considerations**

Waste from unused residues:	Return unused product in original cylinder to supplier. Contact supplier if product guidance is required.
Contaminated packaging:	Return cylinder to supplier.

**I.14 Transport information****Code of Federal Regulations (USA)**

Proper shipping name Class UN/ID No.: Sulfur hexafluoride 2.2 UN1080

**International Air Travel Association**

Proper shipping name Class UN/ID No.: Sulfur hexafluoride 2.2 UN1080

**Intermodal transport of dangerous goods**

Proper shipping name Class UN/ID No.: Sulfur hexafluoride 2.2 UN1080

**Canadian Transport Commission**

Proper shipping name Class UN/ID No.: Sulfur hexafluoride 2.2 UN1080

**Further Information**

Avoid transport on vehicles where the load space is not separated from the driver's compartment. Ensure that the vehicle driver is aware of the potential hazards of the load and knows what to do in the event of an accident or an emergency.

**Annex I**  
(concluded)**I.15 Other information****National Fire Protection Agency rating for SF<sub>6</sub>**

Health: 1  
Fire: 0  
Instability: 0

**Hazardous Materials Information System rating for SF<sub>6</sub>**

Health: 1  
Flammability: 0  
Physical hazard: 2

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