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High-voltage switchgear and controlgear —

Part 303: Use and handling of sulphur hexafluoride (SF6)

National foreword

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High-voltage switchgear and controlgear - Part 303: Use and handling of sulphur hexafluoride (SF_6)

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Appareillage à haute tension -
Partie 303: Utilisation et manipulation
de l'hexafluorure de soufre (SF_6)
(CEI/TR 62271-303:2008)

Hochspannungs-Schaltgeräte
und -Schaltanlagen -
Teil 303: Gebrauch von und Umgang
mit Schwefelhexafluorid (SF_6)
(IEC/TR 62271-303:2008)

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CENELEC
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Foreword

The text of the Technical Report IEC/TR 62271-303:2008, prepared by SC 17A, High-voltage switchgear and controlgear, of IEC TC 17, Switchgear and controlgear, was circulated for voting in accordance with the Internal Regulations, Part 2, Subclause 11.4.3.3 (simple majority) and was approved by CENELEC as CLC/TR 62271-303 on 2009-07-03.

Annex ZA has been added by CENELEC.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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 document (including any amendments) applies.

NOTE Where an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60050-441	- [1]	International Electrotechnical Vocabulary (IEV) - Chapter 441: Switchgear, controlgear and fuses	-	-
IEC 60376	- [1]	Specification of technical grade sulfur hexafluoride (SF_6) for use in electrical equipment	EN 60376	2005 [2]
IEC 60480	- [1]	Guidelines for the checking and treatment of sulphur hexafluoride (SF_6) taken from electrical equipment and specification for its re-use	EN 60480	2004 [2]
IEC 62271-1	- [1]	High-voltage switchgear and controlgear - Part 1: Common specifications	EN 62271-1	2008 [2]
IEC 62271-100	- [1]	High-voltage switchgear and controlgear - Part 100: Alternating current circuit-breakers	EN 62271-100	2009 [2]

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[1] Undated reference.

[2] Valid edition at time of issue.

CONTENTS

INTRODUCTION

SF_6 technology is used in switchgear and controlgear, for more than 30 years. Its application is mainly in electric power equipment for rated voltages exceeding 1 kV up to the highest rated voltages for which switchgear and controlgear are manufactured. It is estimated that several millions of the different types of SF_6-filled units are currently in service.

Three methods for gas containment are technically available, according to IEC 62271-1:

- controlled pressure system;

NOTE 1 Controlled pressure systems are no longer used for new equipment, because of the unacceptable leakage rate (see IEC 62271-203).

- closed pressure system: modern high-voltage electric power equipments. The standardized values for leakage rates are 0,5 % and 1 % per year and per gas-filled compartment;
- sealed pressure system: modern medium-voltage electric power equipments (commercially designated as “sealed for life products” or “hermetically sealed systems”). The tightness of sealed pressure systems is specified by their expected operating life. The expected operating life with regard to leakage performance is specified by the manufacturer. Preferred values are 20, 30 and 40 years.

NOTE 2 To fulfil the expected operating life requirement the leakage rate of the SF_6 sealed pressure systems is considered to be less than 0,1 % per year.

The long experience with the use of SF_6 in switchgear and controlgear evidences that a certain number of elementary precautions and procedures should be adopted in order to achieve operational, safety at work and environmental benefits such as:

- safe operation of the equipment;
- optimisation of resources and tools required;
- minimisation of out-of-service time for equipment;
- standard training of personnel handling SF_6;
- reduction of the amount of gas released during handling operations down to the functional physical limit;
- avoidance of any deliberate release, for example flushing to the atmosphere;
- reduction of SF_6 losses and emissions during commissioning, service, operation and end-of-life treatment to a minimum.

Recently, the latest practical recommendations on the use of SF_6 technology applied to switchgear and controlgear have been published by WG B3.02 of CIGRE Study Committee B3 [1][1]. This information is used to revise IEC 61634 into the present technical report.

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[1] Figures in square brackets refer to the **Bibliography**.

HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

Part 303: Use and handling of sulphur hexafluoride (SF_6)

1 Scope

The scope of this technical report is to address the procedures for safe and environmental compatible handling of SF_6 during installation, commissioning, normal and abnormal operations, disposal at the end-of-life of high-voltage switchgear and controlgear. Storage and transportation of SF_6 are also covered.

These procedures should be regarded as minimum requirements to ensure the safety of personnel working with SF_6 and to minimize the SF_6 emission to the environment.

This technical report generally applies also to gas mixtures containing SF_6.

NOTE 1 For the use of this technical report, the term " high voltage" (reference IEV 601-01-27) is the rated voltage above 1 000 V. However, the term " medium voltage" (reference IEV 601-01-28) is commonly used for distribution systems with voltages above 1 kV and generally applied up to and including 52 kV.

NOTE 2 Throughout this technical report, the term "electric power equipment" stands for "high-voltage and medium voltage switchgear and/or controlgear".

2 Normative references

The following referenced documents are indispensable for the application of this technical report. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-441, *International Electrotechnical Vocabulary (IEV) – Part 441: Switchgear, controlgear and fuses*

IEC 60376, *Specification of technical grade sulphur hexafluoride (SF_6) for use in electrical equipment*

IEC 60480, *Guidelines for the checking and treatment of sulphur hexafluoride (SF_6) taken from electrical equipment and specifications for its reuse*

IEC 62271-1, *High-voltage switchgear and controlgear – Part 1: Common specifications*

IEC 62271-100, *High-voltage switchgear and controlgear – Part 100: Alternating-current circuit-breakers*

3 Terms and definitions

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

NOTE There are many different types of electric power equipment which use SF_6 as a dielectric and/or arc-quenching medium.

3.1
abnormal release of sulphur hexafluoride (SF_6)
release from equipment in service due to a failure in the pressure system

NOTE An abnormal SF_6 release is usually an un-wanted and continuous emission of gas. As soon as an abnormal SF_6 leakage is detected, appropriate measures to locate and eliminate the leak should be immediately arranged.

3.2
handling of sulphur hexafluoride (SF_6)
any process which might involve transfer of SF_6

3.3
evacuation
transfer of a gas different from SF_6 (for example air or N_2) from the gas compartment to the atmosphere. The operation is performed utilising a vacuum pump

3.4
recovery of sulphur hexafluoride (SF_6)
transfer of SF_6 from the gas compartment into a reclaimer or storage container. The operation is normally performed utilising a recovery compressor

3.5
topping-up with sulphur hexafluoride (SF_6)
filling with SF_6 a pre-filled compartment to the SF_6 rated filling pressure

NOTE Pre-filled compartments are closed pressure systems filled in the factory prior to shipment. They contain SF_6 at a typical pressure between 0,12 MPa to 0,15 MPa allowing for a faster and easier commissioning on-site.

3.6
reclaim of sulphur hexafluoride (SF_6)
a series of SF_6 handling including recovery and minimum SF_6 refining process such as filtering dust, by-products, moisture, oil, etc.

NOTE 1 A standard reclaimer is described in 11.1.

NOTE 2 Sometimes the words “reclaiming” or “reclamation” may be used with the same meaning as “reclaim”.

3.7
metal-enclosed switchgear and controlgear
switchgear and controlgear assemblies with an external metal enclosure intended to be earthed, and complete except for external connections
[IEV 441-12-04]

3.8
insulation-enclosed switchgear and controlgear
switchgear and controlgear assemblies with an external insulation enclosure and completely assembled, except for external connections

NOTE The external insulation may be supplied with a (semi-) conducting layer.

[IEV 441-12-06, modified]

3.9
gas-insulated metal-enclosed switchgear
metal-enclosed switchgear in which the insulation is obtained, at least partly, by an insulating gas other than air at atmospheric pressure

NOTE This term generally applies to high-voltage switchgear and controlgear.

[IEV 441-12-05]

3.10
gas-filled compartment

compartment of switchgear and controlgear in which the gas pressure is maintained by one of the following systems:

- controlled pressure system;
- closed pressure system;
- sealed pressure system.

NOTE 1 Several gas-filled compartments may be permanently interconnected to form a common gas-system (gas-tight assembly).

NOTE 2 This definition reproduces 3.6.6.1 of IEC 62271-1.

3.11
controlled pressure system for gas

volume which is automatically replenished from an external compressed gas supply or internal gas source

NOTE 1 Examples of controlled pressure systems are air-blast circuit-breakers or pneumatic operating mechanisms.

NOTE 2 A volume may consist of several permanently connected gas-filled compartments.

NOTE 3 This definition reproduces 3.6.6.2 of IEC 62271-1.

3.12
closed pressure system for gas

volume which is replenished only periodically by manual connection to an external gas source

NOTE 1 Example of closed pressure systems are SF_6 single pressure circuit-breakers.

NOTE 2 This definition reproduces 3.6.6.3 of IEC 62271-1.

3.13
sealed pressure system

volume for which no further gas or vacuum processing is required during its expected operating life

NOTE 1 Examples of sealed pressure systems are tubes of vacuum circuit-breakers or some SF_6 circuit-breakers.

NOTE 2 Sealed pressure systems are completely assembled and tested in the factory.

NOTE 3 This definition reproduces 3.6.6.4 of IEC 62271-1.

3.14
technical grade sulphur hexafluoride (SF_6)

SF_6 gas having a very low level of impurities in accordance with IEC 60376

3.15
used sulphur hexafluoride (SF_6)

gas removed from an electrical equipment, initially filled with SF_6 according to IEC 60376 or IEC 60480. If after filling, the gas is removed for any purpose during the life of the equipment, for example repair, service, maintenance, the gas will be transferred and is considered as used gas

NOTE Annex C provides information regarding the by-products of used SF_6, which occur as gaseous and solid.

3.16
used sulphur hexafluoride (SF_6) suitable for reuse on site

used SF_6 complying with the maximum acceptable impurity level in IEC 60480

NOTE If necessary, service units with appropriate filters and adsorber materials should be used.

3.17
used sulphur hexafluoride (SF_6) suitable for reuse at the gas manufacturer

used SF_6 exceeding the maximum acceptable impurity level in IEC 60480, but complying with the specification for gas reuse given by the gas manufacturer

NOTE If necessary to meet the specification, service units with appropriate filters and adsorber materials should be used.

3.18
used sulphur hexafluoride (SF_6) not suitable for reuse

gas complying with 3.15 but not complying with 3.16, and/or 3.17.

NOTE Used sulphur hexafluoride not suitable for reuse is disposed according to local or international regulations on waste management.

3.19
non-arced sulphur hexafluoride (SF_6)

used sulphur hexafluoride (SF_6) having less than approx. 0,1 % by volume of gaseous by-products

NOTE Non-arced sulphur hexafluoride is typically expected to be in any compartment after filling and prior to energising and/or after insulation testing and/or in insulation compartments which never experienced arcing.

3.20
normally arced sulphur hexafluoride (SF_6)

used sulphur hexafluoride (SF_6) having between approx. 0,1 % by volume and approx. 5 % by vol. of gaseous by-products

NOTE 1 Normally arced sulphur hexafluoride is typically expected to be in circuit breakers/load break switches after normal (load or fault) operations.

NOTE 2 A small amount of solid by-products, mainly metal fluorides and tungsten oxifluorides, may be present as well.

3.21
heavily arced sulphur hexafluoride (SF_6)

used sulphur hexafluoride (SF_6) having more than approx. 5 % by vol. of gaseous by-products

NOTE 1 Heavily arced sulphur hexafluoride is typically expected to be in any gas compartments after internal arc fault and/or circuit breakers/load break switches after interruption failure and/or circuit breakers after successful interruptions of several short circuits at high amplitude in relation with its ratings.

NOTE 2 A large amount of solid by-products, mainly metal fluorides and tungsten oxifluorides, is expected as well.

4 Storage and transportation of SF_6

Storage and transportation of SF_6, either in containers or in electric power equipment is always carried out in accordance with local and international regulations.

NOTE An empty SF_6 container may still contain a residual amount of SF_6. It should be stored and transported in the same way as for a filled container.

4.1 Storage of containers filled with SF_6

In general, SF_6 can be stored in two ways either as a gas at less than 2 MPa or as a liquid up to 5 MPa. Gaseous storage has the advantage of reducing the recovery and filling times but requires large storage volumes and is therefore generally restricted to small volume equipment or used in fixed location gas handling facilities. Liquid storage gives the ability to reduce storage volumes and economically transport large quantities of SF_6.

Containers are handled carefully and stored in a cool, dry, well ventilated area away from flammable or explosive material. They should be protected from direct sunlight, mounted clear of wet ground and secured to prevent falling over. Special valve protections should be adopted to avoid any potential damage on the valve itself.

Containers are refillable (non refillable containers are banned) and clearly labelled to identify their contents; containers containing technical grade SF_6 and used SF_6 suitable for reuse on site should be physically separated from those containing used SF_6 suitable for reuse at the gas manufacturer or used SF_6 not suitable for reuse.

Table 1 gives an overview of all possible storage methods on which a storage container may be based.

Table 1 – Methods for storage of SF_6

Method	Requirements	Features
Gaseous	Typical pressure lower than 2 MPa. SF_6 remains in the gaseous state	Requires relatively small recovery pressure differential (typically 100:1) but needs larger storage volumes. Gas cannot be liquefied in containers for transportation. Therefore it is limited to small quantities (typically 200 kg) and stationary use
Liquid-cooling assisted	Typical pressure equal to 3 MPa. Employs additional cooling system to cool SF_6 after compression, which allows SF_6 to be stored in liquid form	Requires relatively small recovery pressure differential (typically 700:1) but needs cooling aggregate. Performance of cooling aggregate can influence processing speed. Additional maintenance requirements. Limited storage volume required and generally not suitable for transportation
Liquid-pressure only	Typical pressure equal to 5 MPa. SF_6 compressed to 5 MPa liquefies by pressure only	Requires recovery differential of typically 1000:1 but eliminates the need of additional aggregates. Can be used with any storage vessel rated 5 MPa or higher

When used SF_6 is stored on-site, the storage containers comply with local and international regulations on pressurised vessels. Container labelling should be done according to local and international regulations, as well.

NOTE International regulations are published and periodically revised by the Committee of Experts on the Transport of Dangerous Goods (TDG) and on the Globally Harmonized System of Classification and Labelling (GHS) of the Economic Commission for Europe of the United Nations

Table 2 gives an overview of container types and required labelling. For practical reasons it is recommended to preferentially use transportable storage containers, wherever possible.

Table 2 – Container types and labelling required for storage and transportation of SF_6

Gas	Characteristic	Container type	Container labelling
Technical grade SF_6	Liquefied inert gas	**Suitable for liquefied gas up to a pressure of 7 MPa.** NOTE The filling factor for technical grade SF_6 is up to 1,04 kg/l. **Recommendation:** Containers should be marked with a green label or the container should be painted green according to EN 1089-3	**Stencilled on container:** UN 1080, sulphur hexafluoride **Danger label 2.2**
Used SF_6 suitable for reuse on site	Liquefied inert gas	**Suitable for liquefied gas up to a pressure of 7 MPa.** NOTE Due to the inert gas content (for example N_2, O_2), the filling factor is smaller than 0,8 kg/litre (see NOTE 1). **Recommendation:** Containers should be specially coloured to avoid confusion between used and technical grade SF_6 (an orange band on the upper third of the container is suggested)	**Stencilled on container:** UN 3163, sulphur hexafluoride, carbon tetrafluoride or air or nitrogen (see NOTE 2) **Danger label 2.2**
Used SF_6 suitable for reuse at gas manufacturer and/or used SF_6 not suitable for reuse	Liquefied inert gas	Container type and labelling are the same as for used SF_6 suitable for reuse on-site	
	Liquefied gas containing toxic gaseous by-products (see NOTE 3)	Same as for used SF_6 suitable for reuse on site	**Stencilled on container:** UN 3162, sulphur hexafluoride, hydrogen fluoride, thionyl fluoride (see NOTE 2) **Danger label 2.3**
	Liquefied gas containing both toxic and corrosive gaseous by-products (see NOTE 4)	**Special containers approved for storing and transportation of corrosive gases** (such as hydrofluoric acid HF) with a corrosion-proof valve and adapter	**Stencilled on container:** UN 3308, sulphur hexafluoride, hydrogen fluoride, thionyl fluoride **Danger labels 2.3 + 8**

NOTE 1 The filling factor is the weight of SF_6 contained in the container divided by the container volume and is usually specified in kg/litre.

NOTE 2 Only the two most abundant contaminants have to be specified.

NOTE 3 Any used SF_6 containing toxic gaseous by-products can be reclaimed on site to remove the toxic gaseous by-products and allowing an easier transportation.

NOTE 4 Any used SF_6 containing both toxic and corrosive gaseous by-products can be reclaimed on site to remove the toxic and corrosive gaseous by-products and allowing an easier transportation.

4.2 Transportation of containers filled with SF_6

International regulations for shipment of electric power equipment containing SF_6 and/or SF_6 containers are available for transportation by road (ADR), rail (RID), ship (IMDG code), and air (IATA – DGR). These are similar concerning UN numbering, classification, danger labelling, final classification, and transport documentation. However official languages differ as follows:

- ADR: German, French, English;
- RID: English,
- IMDG code: English;
- IATA – DGR: English.

The international regulations for shipment of SF_6 are summarised in Table 3.

Table 3 – International regulations for shipment of SF_6

Gas	Characteristic	Class	Final classification	Transport document
Technical grade SF_6 (see NOTE 1)	Liquefied inert gas	2A	UN 1080 liquefied gas, n.o.s. 2.2	UN 1080 liquefied gas, n.o.s (sulphur hexafluoride) 2.2
Used SF_6 suitable for reuse on site	Liquefied inert gas	Transportation class and danger label are the same as for technical grade SF_6	UN 3163 liquefied gas, n.o.s. 2.2	UN 3163 liquefied gas, n.o.s. (sulphur hexafluoride and air or nitrogen or carbon tetrafluoride) 2.2
Used SF_6 suitable for reuse at gas manufacturer and/or used SF6 not suitable for reuse	Liquefied inert gas	UN number, transportation class, danger label, final classification and transport document are the same as for used SF_6 suitable for reuse on site		
	Liquefied toxic gas (gas containing toxic gaseous by-products) (see NOTE 2)	2T	UN 3162 liquefied toxic gas, n.o.s. 2.3	UN 3162 liquefied gas, toxic, n.o.s. (sulphur hexafluoride and hydrogen fluoride and thionyl fluoride) 2.3
	Liquefied toxic and corrosive gas (gas containing both toxic and corrosive gaseous by-products) (see NOTE 3)	2TC	UN 3308 liquefied toxic and corrosive gas, n.o.s. 2.3 + 8	UN 3308 liquefied gas, toxic, corrosive, n.o.s. (sulphur hexafluoride and hydrogen fluoride and thionyl fluoride) 2.3 + 8

NOTE 1 Avoid any contamination of containers dedicated to technical grade SF_6

NOTE 2 Any used SF_6 containing toxic gaseous by-products can be reclaimed on-site to remove the toxic gaseous by-products and allowing an easier transportation.

NOTE 3 Any used SF_6 containing both toxic and corrosive gaseous by-products can be reclaimed on-site to remove the toxic and corrosive gaseous by-products and allowing an easier transportation.

4.3 Storage and transportation of electric power equipment containing SF_6

Electric power equipments filled with SF_6 are stored and transported according to local and international regulations.

4.4 Responsibilities

The owner of the electric power equipment utilising SF_6 is responsible for the proper use, transportation, and disposal of the equipment and the gas. He is also responsible for record-keeping regarding SF_6 banked in equipment and/or stored in containers as well as emission rates on a yearly basis. This is supported by the original equipment manufacturer and the gas supplier with basic information on the manuals as per IEC 62271-1.

5 Safety and first aid

5.1 General safety rules

Before starting any maintenance/service work in electric power equipment, the detailed state/condition of the equipment should be inspected and reported in detail. In addition to the local safety regulations that are met, at least the following general safety rules should be followed:

- Switch off and isolate.

- Secure against re-closing.
- Verify that equipment is de-energised.
- Earth and short-circuit the equipment.
- Cover or fence off nearby live parts.

Written documents giving permission to work on the electric power equipment should be agreed and signed by both the owner / operator of the equipment and the service provider.

Table 4 lists the major issues to consider when working with SF_6 electric power equipment.

Table 4 – Measures when working with SF_6 electric power equipment

Item	Work in the vicinity of equipment (operation of equipment, visual check, room-cleaning)	Filling, recovering, evacuation of gas compartments	Opening of gas compartments, work on open compartments
Material safety data sheet/operational manuals	Not required	Applicable	Applicable
Training	Applicable (see NOTE)	Applicable	Applicable
SF_6 handling equipment	Not required	Applicable	Applicable
Cleaning/ neutralising equipment	Not required	Not required	Applicable
Personal protection equipment	Not required	Not required	Applicable
NOTE General information should be specified according to type of work and installation, according to local safety regulations.			

A notice stating that open fire, smoking, use of thermal engines, heating to more than 200 °C and welding without special precautions are prohibited and giving first-aid instructions (see 5.3) should be displayed while SF_6 is being handled in any location.

When a gas compartment is opened after the electric power equipment has been in service, in order to avoid contact with the fine solid by-products, which may be present, personnel should wear suitable protective clothing. Particular attention should be given to protecting the eyes and the respiratory tract. Personnel working in or near to opened gas compartments, which have contained normally arced and/or heavily arced SF_6:

- use suitable tools and equipment;
- observe high standards of personal hygiene;
- clean themselves and their equipment using disposable materials, before leaving the work area;
- remove protective clothing and wash themselves thoroughly as soon as possible after having left the work area;
- ensure that clothing, tools and components which have been in contact with by-products are securely packed in sealed bags or other sealed containers and are subsequently treated to neutralise any residues.

5.1.1 Protection of personnel

SF_6 is handled by certified personnel, only. Different training modules may be adopted, depending on the kind of work to be performed on the electric power equipment (see Clause 6).

A specific training covering the recovering of used SF_6 from a gas-filled compartment is requested for personnel opening and/or entering the gas compartment. The operating instruction manual of the equipment provided by the original equipment manufacturer (OEM) should be strictly followed.

Table 5 gives an overview of the potential risks, safety precautions as well as safety equipment and tools required when opening and/or entering a gas compartment. No substantial difference between indoor and outdoor conditions is given as the operator opens and/or enters the compartment.

Table 5 – Safety measures when opening and/or accessing gas compartments

Item	Any compartment which contained normally or heavily arced SF_6	Any compartment which contained non-arced SF_6
Potential risk	Fumes of cleaning substances O_2 starvation Remaining used SF_6 Residual reactive gaseous by-products Solid by-products and adsorber materials	Fumes of cleaning substances O_2 starvation Remaining used SF_6 or other gas from production process
Safety precaution	Removal of solid by-products and adsorber materials Ventilation Measurement of O_2 concentration when entering Wear personal protective equipment Protect solid by-products against hydrolysis	Ventilation Measurement of O_2 concentration when entering
Safety equipment and tools	Suction ventilator or vacuum cleaner O_2 concentration measuring device Single use protective overalls, protective footwear, hair cap Acid proof safety gloves Full face mask (preferred) or, at least, breathing protective mask Protective goggles Environmental protection against rain and/or wind (outdoor only)	Suction ventilator or vacuum cleaner O_2 concentration measuring device

Like any gas but oxygen, a concentration greater than 19 % by vol. of SF_6 in the air is considered as potential risk of asphyxiation. This is because it reduces the oxygen concentration down to 16 % by vol., which is usually considered as the threshold for asphyxiation. As a consequence it is recommended that the oxygen content in the gas compartment be measured prior to accessing. In addition to that, the oxygen content in the ambient may be checked when working in confined spaces.

Eating, drinking and smoking are not allowed when accessing or opening a gas compartment. It is recommended that clothes should be changed and the skin washed as soon as possible after the work to prevent potential danger of irritation or burns.

5.1.2 Handling of contaminated safety equipment and tools

Equipment and tools, which have been in contact with solid by-products and/or adsorber materials is considered as contaminated. They are collected afterwards and placed in plastic bags. The plastic bags are sealed with tape and labelled. Disposal is done according to the local regulations.

Reusable equipment and/or tools should be washed and neutralised in a water/soda solution with 10 % by weight liquid soda or equivalent and then rinsed with clean water. Examples of neutralising solutions are given in Table 6.

Disposal of both the water/soda solution and the washing water is done according to the local regulations.

Table 6 – Neutralising solutions

Active agent	**Formula**	**Concentration Kg/100 l**	**T_1 (see NOTE 1)** Hours	**T_2 (see NOTE 2)** Hours	**Reference**
Lime	$Ca(OH)_2$	Saturated	Not applicable	24	[2]
Sodium carbonate (washing soda)	Na_2CO_3	1,1	Not applicable	24	[3]
		3	Wash	Not applicable	[2]
		10 (NOTE 3)	Not applicable	0,25	[4]
		10-14 (NOTE 3)	1	48	[5]
		3	Not applicable	Not applicable	[6]
Sodium bicarbonate	$NaHCO_3$	1 (NOTE 4)	Not applicable	Not applicable –	[4]

NOTE 1 Reusable safety equipment, tools, gas compartments, and internal parts of compartments which contained normally arced SF_6 should, where practicable, be treated with a neutralising solution for a time period T_1. They should then be rinsed with clean water.

NOTE 2 Reusable safety equipment, tools, gas compartments, and internal parts of compartments which contained heavily arced SF_6 should, where practicable, be treated with a neutralising solution for a time period T_2. They should then be rinsed with clean water.

NOTE 3 When using alkaline solutions at such high concentrations, care should be taken to avoid contact with the skin and eyes.

NOTE 4 Recommended for washing the skin.

5.1.3 Pressurised equipment and tools or measuring devices

As any pressurised gas, a sudden volume expansion results in a local temperature drop and may cause freezing. Suitable gloves and protective goggles should be worn when working on high-pressure piping, valves or connectors, during filling operations.

All equipment and tools used during SF_6 handling potentially contain gaseous or liquid SF_6 under high pressure. They should be handled with care.

5.1.4 Personal safety and protective equipment

The use of personal safety and protective equipment is not related to the presence of the SF_6 electric power equipment itself. Standard safety shoes, helmet, and protective goggles may be required according to local regulations to get in the vicinity of the switchgear.

In case of abnormal release of SF_6 due to external fire or internal arc fault, additional safety rules apply for entering a switchgear room, according to 5.2.

Depending on the kind of work to be performed on site and according to Table 5, workers engaged in handling SF_6 are provided with the following personal safety and protective equipment:

- Protective gloves: acid resistant gloves made of for example neoprene, PVC, rubber. In addition to protective gloves the use of protective creams is recommended;

- Protective goggles: chemical type industrial goggles according to local regulations (for example European Standard EN 166);
- Breathing protective mask: to be used in conjunction with protective goggles, the breathing protective mask helps to protect mouth and nose against dust and should be used in case of exposure to minor dusty areas, only;
- Full face mask: for short-term inspection and work where ventilation can be provided but where the concentration of by-products may exceed the appropriate maximum level, a face mask with changeable active charcoal filter is used according to local regulations (for example European Standards EN 140, EN 141 and EN 143 specify masks, gas filters and particle filters, respectively. Combined filters of type A2/B2/E2/K2/P3 manufactured to these standards are available and are able to provide protection against by-products including particles with a diameter greater than 1 µm);
- Single use protective overall: dust proof protective clothes to wear over normal clothes, shoe covers, hair cap. Pocket-less, hooded, non-permeable (for example bonded polypropylene) disposable industrial grade overalls having elastic ankle and wrist grips, overlapping the footwear and gloves;
- Respirator: when entering indoor applications after major leakage or internal arcing when the concentration of O_2 or the amount of by-products are at unsafe levels, a respirator is used according to local regulations (for example European Standard EN 136);
- O_2 concentration measurement device for permanent monitoring the O_2 content in the environment;
- Environmental protection for outdoor: temporary shelter to prevent the ingress of rain and the wind dispersing solid by-products (if any) while the gas compartment is open.
- Vacuum cleaner: a high efficiency dedicated vacuum cleaner, equipped with a filter capable of trapping particles in the range of 1 µm, and a non-metallic open-ended nozzle according to local regulations (for example a type H machine in accordance with BS 5415, Supplement No. 1, 1986).
- Suction ventilator: equipment for forced ventilation of enclosed spaces and other inaccessible areas. Such equipment might be portable or permanently installed, depending on the size of the installation.

5.1.5 Facilities and services

Where gas compartments containing used SF_6 have to be emptied and opened, it is desirable that adequate washing facilities for workers be available, and a supply of water for preparing cleaning solutions may be required.

5.2 Additional safety measures in case of abnormal release of SF_6 due to external fire or internal arc fault

General safety recommendations to adopt when working with SF_6 on site are given in the 5.1. The present subclause describes additional safety measures in case of abnormal release of SF_6 due to external fire or internal arc fault.

Under those circumstances, personnel trained on modules C1 or C2 (see 6.2.4 and 6.2.5, respectively) are allowed to enter and clean the switchgear room or to access the electric power equipment. Table 7 gives an overview of the potential risks, safety precautions as well as safety equipment and tools required.

NOTE Fire fighting crews are allowed to enter the switchgear room in the terms described in the local regulations.

Table 7 – Additional safety measures

Item	Abnormal release of heavily arced SF_6	Abnormal release of non-arced or normally arced SF_6
Potential risk	Fumes of cleaning substances O_2 starvation SF_6 abnormally released Residual reactive gaseous by-products Solid by-products	Fumes of cleaning substances O_2 starvation SF_6 abnormally released
Safety precaution	Removal of solid by-products Ventilation Measurement of O_2 concentration when entering Wear personal protective equipment	Ventilation Measurement of O_2 concentration when entering
Safety equipment and tools	Suction ventilator or vacuum cleaner O_2 concentration measuring device Single use protective clothes, shoe covers, hair cap Acid proof safety gloves Full face mask (preferred) or, at least, breathing protective mask and protective goggles	Suction ventilator or vacuum cleaner O_2 concentration measuring device

The same rules apply to areas below the level at which the release occurred, poorly ventilated or unventilated areas (for example cable trenches, inspection pits, drainage systems). Outdoor equipment needs standard measures for outdoor conditions to be applied (for example rain protection, wind protection). Natural ventilation is normally enough to prevent the potential risk of O_2 starvation.

A second person being in continuous visual and acoustical contact should be present, when entering areas which might have a low oxygen concentration.

5.3 First aid equipment and treatment

First aid equipments are:

- Normal industrial first-aid equipment including eyewash equipment containing a saline solution
- Means for contacting emergency services
- Guidance for medical doctors.

The application of the general safety rules (see 5.1) should minimise the likelihood of accidents. In case of an accident, first aid treatment should be applied as reported in 5.3.1 through 5.3.3.

5.3.1 Irritation of the skin

In case of signs of skin irritation, the personnel are removed from the area. Contaminated clothing are removed and the affected part washed with cool running water. Medical professional advice is sought.

5.3.2 Irritation of the eyes

In case of signs of eyes irritation, the personnel leave the area. Irrigation of the eye or eyes is carried out immediately and continued until a medical professional advises the patient to stop.

5.3.3 Breathing difficulty

Personnel should immediately leave the area to fresh air. Contaminated clothing should be removed and the patient should be covered with a blanket and kept still and under observation. Emergency medical assistance is called without delay. In case of breathing failing, artificial respiration should be given by trained and qualified personnel.

6 Training and certification

6.1 General

By the nature of the technology used for electric power equipment utilising SF_6, operational safety and environmental aspects are intrinsically and tightly coupled together and therefore should be treated at the same time.

The following subclauses are focused on trainings performed to assure that operational safety requirements and environmental aspects are met concerning electric power equipment utilising SF_6.

Work on electric power equipment involving gas handling (for example development, manufacturing, testing, erection, commissioning, maintenance, service, and dismantling at the end-of-life) is performed either by certified personnel or under the supervision of certified personnel. For the personnel involved, training is mandatory. Training can be done in different locations (for example special training centre of the user, in the factory or on site during erection, commissioning and maintenance of installed equipment).

Given the specific nature of the electric industry and equipments, safety and continuity of service are very important. With the exception of the general training module (module A – awareness, see 6.2.1), the scope of the training is related to a specific design (for example high-voltage life tank breaker, medium-voltage switchgear, high-voltage gas insulated switchgear) and different designs require different trainings to be certified.

NOTE The successful training completion should be checked by an “in-house” examination and recorded by certificates of competence or other written confirmation related to the training module being issued by the “in-house” training body.

In all cases, the training should be based on local regulations, operating instruction manuals of the equipment, instruments datasheets, international standards, the present technical report, and CIGRE brochures.

6.2 Training modules

With respect to the different pressure systems according to definitions given in 3.12 and 3.13, the individual training programme and its composition of modules should be chosen accordingly considering the fact that sealed pressure systems, by definition, do not require gas handling for maintenance during its entire operating life.

Workers handling SF_6 should be familiar with safety, legal and environmental aspects, the properties of the gas, the gas handling tools and equipment, and procedures to assure the continuity of service and minimise SF_6 emissions.

The trainings are organised in modules with the intention of satisfying the needs given by the kind of work to be performed on the electric power equipment. They are:

- Module A: Awareness
- Module B1: Maintenance not implying gas recovery
- Module B2: Installation and commissioning

- Module C1: Maintenance implying gas recovery (for example extension during the operating life included)
- Module C2: Decommissioning of electric power equipment at the end-of-life.

The modules are described in a detailed manner in the following subclauses.

6.2.1 Module A – Awareness

This module provides the basic level of training required and applies to all functions involved, particularly for:

- Companies' staff being entrusted by their management with the responsibility for processes and related own or third parties' personnel operating SF_6 filled equipment, independently from the question whether SF_6 handling is involved or not;
- All personnel working with SF_6 filled equipment, independently from the question whether SF_6 handling is involved or not.

No prerequisites are requested for attending the training.

NOTE All personnel working in the proximity to SF_6 filled equipment should be made aware according to the general safety rules given in 5.1.

The training covers the following aspects:

- Basic knowledge of relevant environmental issues (for example climate change, Kyoto Protocol, Global Warming Potential, see Annex B);
- Environmental relevance of SF_6 emissions and mitigation approaches [12];
- Physical, chemical and environmental characteristics of SF_6 (see Annex A);
- Use of SF_6 in electric power equipment;
- Existence of local regulations and international standards;
- Personnel safety and first aid (for example local regulations, emergency plans and instructions in case of for example asphyxiation, internal arc fault), (see Clause 5);
- Design of electric power equipment (properties and application/functionality).

6.2.2 Module B1 – Maintenance not implying gas recovery

This module provides the first intermediate level of training required for personnel who are requested to:

- Check the SF_6 quality on-site;
- Perform a SF_6 re-filling operation;

The certification concerning module A is requested to attend the training. In alternative to that, a combined training session covering both modules A and B1 can be arranged.

The training covers the following aspects:

- Existence of local regulations and international standards in relation to the tasks;
- SF_6 quality according to IEC 60376 (technical grade SF_6) and IEC 60480 (SF_6 for re-use);
- The instruction manuals given by the Original Equipment Manufacturer in relation to the tasks;
- Personnel safety and first aid (for example safety equipment required for personal protection), (see Clause 5);
- Types of SF_6 filled compartments (see 3.10, 3.11, 3.12, and 3.13);
- Instruments and procedures for checking the SF_6 quality (see 8.2 and 11.3);

- Procedures for re-filling of closed pressure systems (see 8.1);
- Leak detection methods and repair techniques;
- Categories for SF_6 reclaiming and reuse (see 3.14, 3.15, 3.16, 3.17, 3.18, 3.19, 3.20, and 3.21);
- Storage and transportation of SF_6 (see Clause 4);
- Monitoring of SF_6 gas and appropriate recording of data related to local environmental obligations.

6.2.3 Module B2 – Installation and commissioning

This module provides the second intermediate level of training required for personnel who are requested to installing and commissioning of electric power equipment on-site.

The certification concerning module B1 is requested to attend the training. In alternative to that, a combined training session covering modules A, B1 and B2 can be arranged.

The training covers the following aspects:

- Existence of local regulations and international standards in relation to the tasks;
- The instruction manuals given by the Original Equipment Manufacturer in relation to the tasks;
- Personnel safety and first aid (for example working on open gas compartments in relation to the task) (see Clause 5);
- Procedures for air evacuation and SF_6 filling (see 7.1);
- Procedures for topping-up with SF_6 (see 7.2);
- Procedures for recovery and reclaiming of non-arced SF_6 (see 9.1);
- SF_6 handling equipments in relation to the tasks (see Clause 11).

6.2.4 Module C1 – Maintenance implying gas recovery

This module provides the first advanced level of training required for personnel who are requested to:

- Perform maintenance of electric power equipment utilising SF_6, including gas recovery, reclaiming as well as appropriate handling of by-products;
- Provide further extension of the electric power equipment during its operating life.

The certification concerning module B1 is requested to attend the training. In alternative to that, a combined training session covering modules A, B1, and C1 can be arranged. Module B2 can be added as an option.

The training covers the following aspects:

- Existence of local regulations and international standards in relation to the tasks;
- The instruction manuals given by the original equipment manufacturer in relation to the tasks;
- Personnel safety and first aid (for example safety equipment required for personal protection, working on open gas compartments in relation to the task, neutralising and handling of by-products);
- Procedures for entering the switchgear room in case of abnormal release of SF_6 due to fire or internal arc fault (see 5.2);
- Procedures for recovery and reclaiming of normally and heavily arced SF_6 (see 9.1 and 9.2);
- SF_6 handling equipments in relation to the task (see Clause 11);

- Procedures for cleaning from by-products and neutralisation (see 5.1.2);
- Handling of safety equipment and tools which have been in contact with solid by-products (see 5.1.2).

6.2.5 Module C2 – Decommissioning of electric power equipment at the end-of-life

This module provides the second advanced level of training required for personnel who are requested to decommissioning the electric power equipment at the end-of-life.

The certification concerning module C1 is requested to attend the training. In alternative to that, a combined training session covering modules A, B1, C1, and C2 can be arranged. Module B2 can be added as an option.

The training covers the following aspects:

- Existence of local regulations and international standards in relation to the tasks;
- The instruction manuals given by the original equipment manufacturer in relation to the tasks;
- Transportation of the power electric equipment to the dismantling site, if applicable (see 4.3);
- Dismantling of equipment and part sorting (see Clause 10);
- Instructions given by the original equipment manufacturer on the use of tight drilling systems for recovering SF_6 from the electric power equipment, if applicable.

6.3 Certification

Successful completion of training leads to in-house certification, where “in-house certification”, means a certificate of competence or other written confirmation issued by an employer to such of his own employees or external persons who have satisfactorily completed a course of training, relating to relevant work. Theoretical and/or practical examination sessions are performed to prove the skill and the ability gained.

Records shall be retained so as to:

- Identify the training content;
- Identify which task and equipment design personnel have been certified for (for example SF_6 recovery);
- Restrict task performance (for example SF_6 recovery for a certain design) to the personnel who have been certified for (for example modules C1 and C2);
- Sustain a high level of expertise.

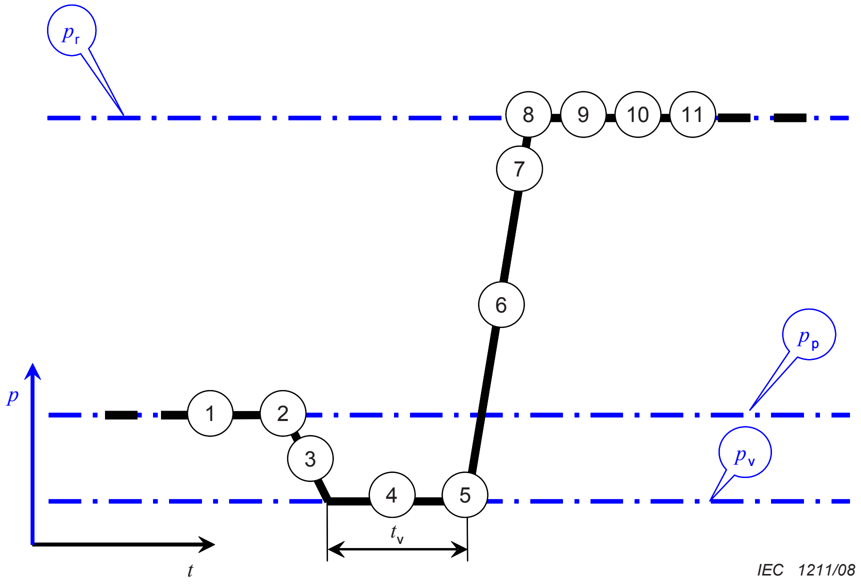
7 SF_6 handling during installation and commissioning

This clause provides guidance for working with technical grade SF_6, according to IEC 60376 or used SF_6 suitable for reuse on site, according to IEC 60480 i.e. when a gas compartment is filled, after the switchgear and/or controlgear has been installed on site.

7.1 Evacuation, filling and checking the SF_6 quality after filling

This subclause applies to switchgear compartments of pressure systems that currently contain a gas different from SF_6 (typically air or N_2) at ambient pressure or slightly overpressure (typically 0,1 MPa to 0,15 MPa).

Unless otherwise specified by the original equipment manufacturer in the operating instruction manual, the following detailed sequence of operations for air/N_2 evacuation and SF_6 filling in each compartment is performed according to Figure 1. Additional details are in Table 8.



Key

1	Prepare SF_6 handling equipment
2	Adsorber installation
3	Evacuation
4	Residual air and/or moisture content
5	Documentation
6	Filling with SF_6
7	Documentation
8	Pressure/density sensor inspection
9	Tightness inspection
10	SF_6 quality checking
11	Documentation
P_r	SF_6 rated filling pressure
p_p	Initial pressure in the gas compartment
p_v	Evacuation pressure < 2 kPa
t_v	Evacuation time ≥ 30 min

Figure 1 – Commissioning or re-commissioning of SF_6 compartments

Table 8 – Commissioning or re-commissioning of SF_6 compartments

Step		Procedure
1	Prepare SF_6 handling equipment	Check that the SF_6 reclaimer is working properly and the gas connections are clean and dry to avoid contamination. Check the validity of the calibration of instruments subject to calibration.
2	Adsorber installation	Quickly insert the adsorber materials in the compartment. Start evacuation immediately afterwards.
3	Evacuation	Connect the vacuum pump and leave it running for at least 30 min. after an evacuation pressure lower than 2 kPa has been reached in the gas compartment.
4	Residual air and/or moisture content	Disconnect the vacuum pump and read the pressure gauge. The evacuation pressure should remain lower than 2 kPa.
5	Documentation	Record at least the manufacturer and serial number and/or the identification of the gas compartment, the evacuation pressure (i.e. the residual air content), ambient temperature and date for further reference.
6	Filling with SF_6	Connect the SF_6 container and fill the compartment until the SF_6 rated filling pressure is reached. Use a safety valve and a calibrated gauge to avoid overfilling (see NOTES 1 and 2).
7	Documentation	Record at least the manufacturer and serial number and/or the identification of the gas compartment, the final filling pressure, ambient temperature and date for further reference.
8	Pressure/density sensor inspection	Check the functionality of the pressure/density sensor. The operation can be performed during the filling operation.
9	Tightness inspection	Check the tightness of at least all permanent connections made on site as requested by the original equipment manufacturer in the operating instruction manual.
10	SF_6 quality checking	Wait for the time specified by the original equipment manufacturer in the operating instruction manual before measuring the moisture content and the SF_6 percentage (see NOTE 3).
11	Documentation	Record at least the manufacturer and serial number and/or the identification of the gas compartment, the functionality of the pressure/density sensor, the moisture content, the SF_6 content, ambient temperature and date for further reference.

NOTE 1 SF_6 to be introduced into the gas compartment should be either technical grade SF_6 or used SF_6 suitable for reuse on site.

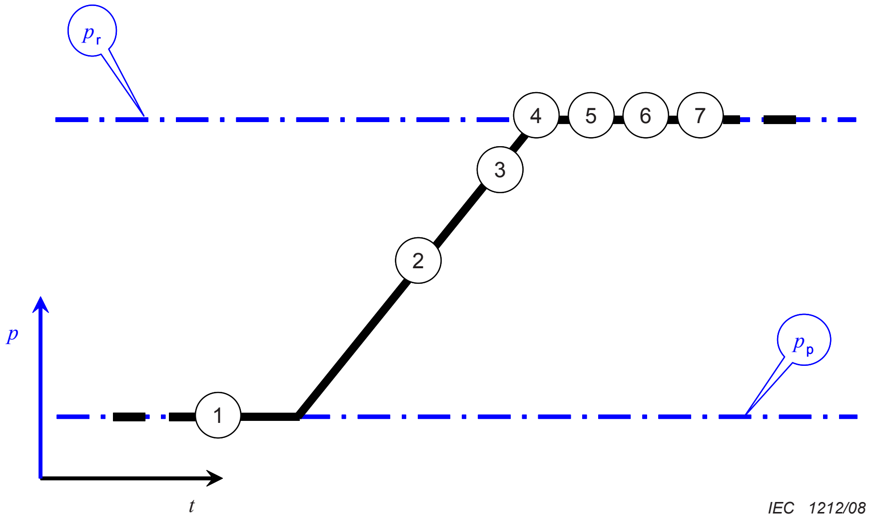
NOTE 2 No SF_6 check is required if the gas comes from the supplier in sealed containers, or if the gas is stored in sealed containers with an appropriate label or certificate to guarantee the gas is suitable for reuse. In all other cases, the SF_6 quality should be checked prior to the filling operation. The SF_6 quality check comprises moisture content, SF_6 percentage, and residual acidity content.

NOTE 3 If the gas compartment has a small volume, refilling after SF_6 quality checking may be required.

7.2 Topping-up of SF_6 pre-filled compartments to the rated pressure/density

This subclause applies to compartments of pressure systems pre-filled in the factory prior to shipment. They contain SF_6 at above atmospheric pressure (typically 0,12 MPa to 0,15 MPa), allowing for a faster and easier commissioning on-site.

Unless otherwise specified by the Original Equipment Manufacturer in the operating instruction manual, the following detailed sequence of operations for SF_6 topping-up in each pre-filled compartment is performed according to Figure 2. Additional details are in Table 9.



Key

1	Prepare SF_6 handling equipment
2	Topping-up with SF_6
3	Documentation
4	Pressure/density sensor inspection
5	Tightness inspection
6	SF_6 quality checking
7	Documentation
p_r	SF_6 rated filling pressure
p_p	Initial SF_6 pressure in the gas-filled compartment

Figure 2 – Topping-up of SF_6 pre-filled compartments to the rated pressure/density

Table 9 – Topping-up of SF_6 pre-filled compartments to the rated pressure/density

Step		Procedure
1	Prepare SF_6 handling equipment	Check that the gas connections are clean and dry, hoses are evacuated and no leaks on connection fittings exist to avoid contamination. Check the validity of the calibration of instruments subject to calibration
2	Topping-up with SF_6	Connect the SF_6 container and fill the compartment until the SF_6 rated filling pressure is reached. Use a safety valve and a calibrated gauge to avoid overfilling (see NOTES 1 and 2)
3	Documentation	Record at least the manufacturer and serial number and/or the identification of the gas compartment, the final filling pressure, ambient temperature and date for further reference
4	Pressure/density sensor inspection	Check the functionality of the pressure/density sensor. The operation can be performed during the filling operation
5	Tightness inspection	Check the tightness of at least all permanent connections made on site as requested by the Original Equipment Manufacturer in the operating instruction manual
6	SF_6 quality checking	Wait for the time specified by the Original Equipment Manufacturer in the operating instruction manual before measuring the moisture content and the SF_6 percentage (see NOTE 3)
7	Documentation	Record at least the manufacturer and serial number and/or the identification of the gas compartment, the functionality of the pressure/density sensor, the moisture content, the SF_6 content, ambient temperature and date for further reference

NOTE 1 SF_6 to be introduced into the gas compartment should be either technical grade SF_6 or used SF_6 suitable for reuse on site.

NOTE 2 No SF_6 check is required if the gas comes from the supplier in sealed containers. In all other cases, the SF_6 quality is checked prior to the filling operation, or if the gas is stored in sealed containers with an appropriate label or certificate to guarantee the gas is suitable for reuse. The SF_6 quality check comprises moisture content, SF_6 percentage, and residual acidity content.

NOTE 3 If the gas compartment has a small volume, refilling after SF_6 quality checking may be required.

7.3 Filling sealed pressure systems

The large majority of medium-voltage switchgear and/or controlgear are sealed pressure systems, as defined in 3.13. Typically this type of equipment is filled with SF_6 in the factory and no further SF_6 handling is required during its expected operating life.

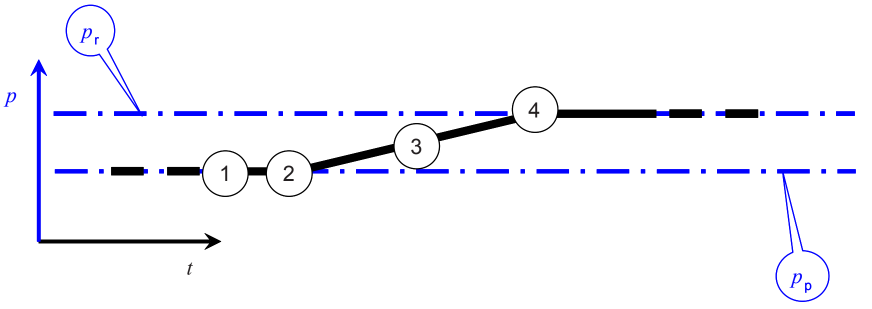
NOTE Under some abnormal circumstances (for example in case of damage) it might be required to re-fill or re-commission the equipment on-site. The original equipment manufacturer should be contacted on purpose.

8 SF_6 handling during normal service life

8.1 Re-filling of SF_6 to the nominal pressure/density

This subclause applies to compartments (usually indicated by the first alarm/indication of the pressure/density monitor) of closed pressure systems to assure continuity of service. In case of an abnormal leak, appropriate corrective measures to locate and eliminate the leak are immediately arranged.

Unless otherwise specified by the original equipment manufacturer in the operating instruction manual, the following detailed sequence of operations for SF_6 re-filling in each compartment is performed according to Figure 3. Additional details are in Table 10.



IEC 1213/08

Key

1	Identify the nature of the leak	4	Documentation
2	Prepare SF_6 handling equipment	p_r	SF_6 rated filling pressure
3	Re-filling with SF_6	p_p	Initial SF_6 pressure in the gas-filled compartment

Figure 3 – SF_6 re-filling to the nominal pressure/density

Table 10 – SF_6 re-filling to the nominal pressure/density

Step		Procedure
1	Identify the nature of the leak	Check the last time the gas compartment was re-filled to understand whether the leak is abnormal
2	Prepare SF_6 handling equipment	Check that the gas connections are clean and dry, hoses are evacuated and no leaks on connection fittings exist to avoid contamination. Check the validity of the calibration of instruments subject to calibration
3	Re-filling with SF_6	Connect the SF_6 container and fill in the compartment until the SF_6 rated filling pressure is reached. Use a safety valve and a calibrated gauge to avoid overfilling (see NOTES 1 and 2)
4	Documentation	Record at least the manufacturer and serial number and/or the identification of the gas compartment, the final filling pressure, ambient temperature and date for further reference

NOTE 1 SF_6 to be introduced into the gas compartment is either technical grade SF_6 or used SF_6 suitable for reuse on site.

NOTE 2 As the amount of SF_6 used for re-filling is very small in comparison to the amount of SF_6 in the related compartment, it is not necessary to perform a SF_6 quality check after the re-filling operation.

8.2 Checking the SF_6 quality

The measurement of the SF_6 quality is usually done on-site, using portable equipment. Off-site analysis may exceptionally be performed to cross-heck unsatisfactory on-site results, by sampling the gas and sending it to a qualified chemical laboratory.

Typical SF_6 quality checks according to IEC 60480 are moisture content (for example water content in mg/kg), SF_6 percentage (for example air and/or CF_4 in % vol.), and total reactive gaseous by-products (for example total amount of reactive gasses in µl/l).

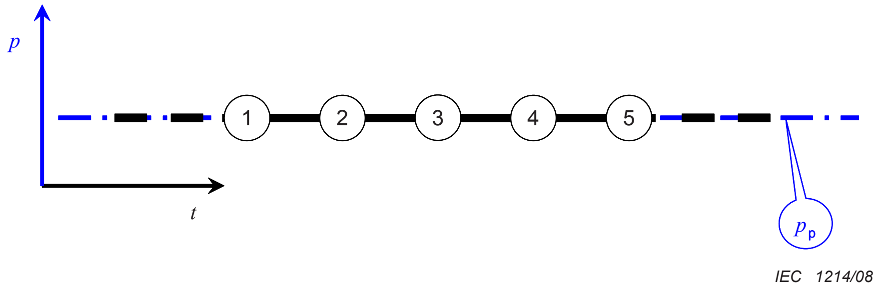
The total reactive gaseous by-products are checked first to prevent damage of other portable equipment, if the history of the gas-filled compartment is unknown or if the gas-filled compartment contains heavily arced SF_6.

8.2.1 Measurement of the SF_6 quality with portable equipment

This subclause applies to SF_6 filled compartments of controlled and/or closed pressure systems or SF_6 filled containers to check the quality of the gas with portable equipment.

Unless otherwise specified by the Original Equipment Manufacturer in the operating instruction manual, the following detailed sequence of operations for an on-site SF_6 quality check is performed according to Figure 4. Additional details are in Table 11.

Characteristics of portable equipments are described in Clause 11.



Key

1	Prepare portable equipment	4	Disconnect the portable equipment
2	Connect the portable equipment	5	Documentation
3	Read the portable equipment	p_p	SF_6 pressure in the gas-filled compartment

Figure 4 – Checking the SF_6 quality on-site

Table 11 – Checking the SF_6 quality on-site

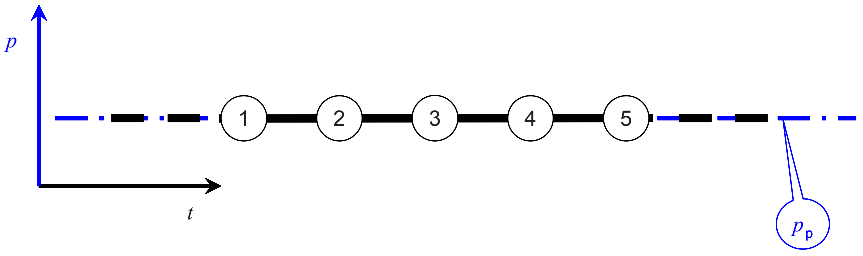
Step		Procedure
1	Prepare portable equipment	Check that the portable equipment is working properly; and the gas connections are clean and dry, hoses are evacuated and no leaks on connection fittings exist to avoid any false measurements. Check the validity of the calibration of instruments subject to calibration. Use short connections to minimise SF_6 release
2	Connect the portable equipment	Connect the portable equipment. Make tight connections and establish gas flow
3	Read the portable equipment	Refer to the operating instruction manual provided by the portable equipment manufacturer
4	Disconnect the portable equipment	Stop the gas flow and disconnect the portable equipment (see NOTE)
5	Documentation	Record at least the manufacturer and serial number and/or the identification of the gas compartment, the reading and the date for further reference
NOTE If the gas compartment has a small volume, refilling after SF_6 quality checking may be required.		

8.2.2 Sampling and shipment of SF_6 for off-site analysis

This subclause applies to SF_6 filled compartments of controlled and/or closed pressure systems or SF_6 filled containers to cross-check unsatisfactory SF_6 quality measurements on-site.

Unless otherwise specified by the Original Equipment Manufacturer in the operating instruction manual, the following detailed sequence of operations for SF_6 sampling and shipment is performed according to Figure 5. Additional details are in Table 12.

Characteristics of cylinders for SF_6 samples are described in 11.4.



IEC 1215/08

Key

1	Prepare SF_6 sampling equipment	4	Disconnect the sampling cylinder
2	Documentation	5	Shipment
3	Connect the sampling cylinder	p_p	SF_6 pressure in the gas-filled compartment

Figure 5 – SF_6 sampling and shipment

Table 12 – SF_6 sampling and shipment

Step		Procedure
1	Prepare SF_6 sampling equipment	Evacuate the sampling cylinder (see NOTE 1). Check that the gas connections are clean and dry, hoses are evacuated and no leaks on connection fittings exist to avoid contamination of the sample and use short connections to minimise SF_6 release
2	Documentation	Tag the sampling cylinder with at least the following information: the manufacturer and serial number and/or the identification of the gas compartment, date, pressure, and ambient temperature
3	Connect the sampling cylinder	Connect the sampling cylinder. Make tight connections and establish gas flow
4	Disconnect the sampling cylinder	Stop gas flow and disconnect the sampling cylinder (see NOTE 2)
5	Shipment	Transportation to the laboratory is done in accordance to local and international regulations, as described in 4.2
NOTE 1 For sampling cylinders, see 11.4. NOTE 2 If the gas compartment has a small volume, refilling after SF_6 quality checking may be required.		

9 SF_6 recovering and reclaiming during maintenance

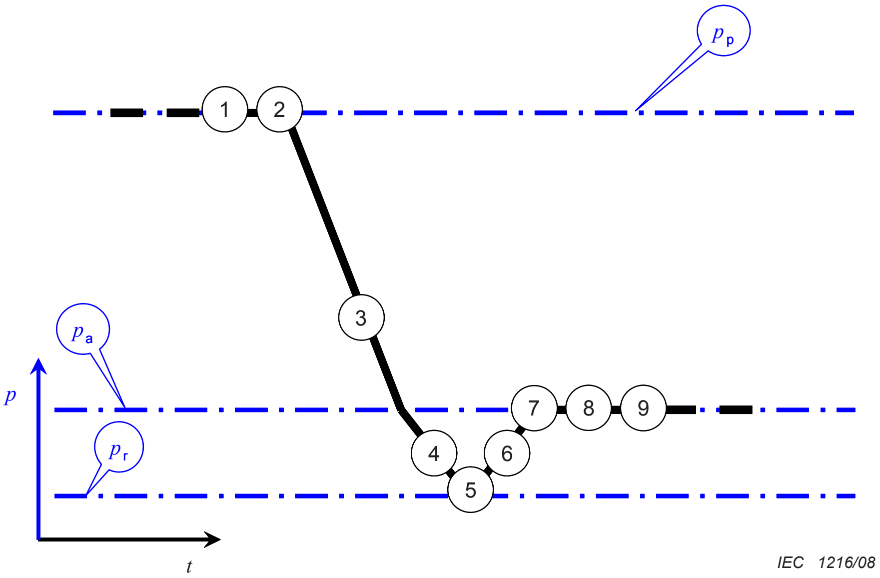
The clause contains the procedures for recovering and reclaiming SF_6 from any gas-filled compartment during maintenance.

9.1 Recovery and reclaiming of SF_6 from any compartment of controlled and/or closed pressure systems containing non-arced and/or normally arced SF_6

This subclause applies to any compartment of controlled and/or closed pressure systems containing non-arced and/or normally arced SF_6, when it is recovered for maintenance.

Unless otherwise specified by the original equipment manufacturer in the operating instruction manual, the following detailed sequence of operations for SF_6 recovery from each compartment are performed according to Figure 6. Additional details are in Table 13.

The safety rules given in 5.1 are strictly followed.



IEC 1216/08

Key

1	Prepare SF_6 handling equipment	7	Open the gas compartment
2	Connect filters	8	Remove solid by-products and adsorbers when present
3	SF_6 recovery	9	Neutralisation, if required
4	Minimise residual SF_6 content	p_p	SF_6 pressure in the gas-filled compartment
5	Documentation	p_a	Atmospheric pressure
6	Flooding with air	p_r	SF_6 residual pressure < 2 kPa

Figure 6 – Recovering and reclaiming from any compartment of controlled and/or closed pressure systems containing non-arced and/or normally arced SF_6

Table 13 – Recovering and reclaiming from any compartment of controlled and/or closed pressure systems containing non-arced and/or normally arced SF_6

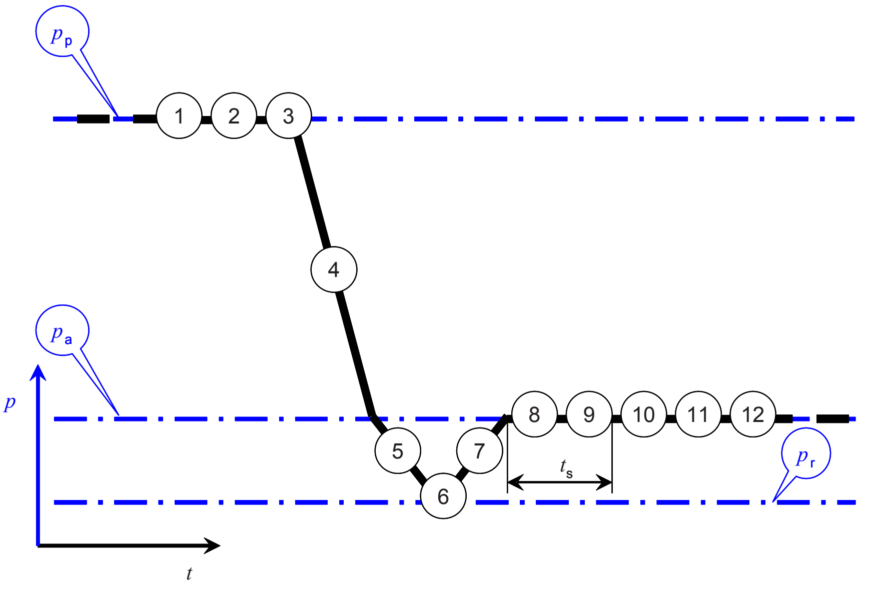
Step		Procedure
1	Prepare SF_6 handling equipment	Check that the SF_6 reclaimer is properly working, the filters and pre-filters are still active, and the gas connections are clean and dry, hoses are evacuated and no leaks on connection fittings exist to avoid contamination. Check the validity of the calibration of instruments subject to calibration
2	Connect filters	Connect the pre-filter between the gas-filled compartment and the compressor and the filter between the compressor and the storage container
3	SF_6 recovery	Connect the gas-filled compartment. Use the main compressor stage as soon as the SF_6 residual pressure in the compartment approaches the pressure in the storage container. Use a safety valve and a calibrated gauge to avoid overfilling of the storage container (see NOTE)
4	Minimise residual SF_6 content	Connect the auxiliary compressor stage when the SF_6 residual pressure in the compartment approaches 100 kPa and leave it running until a pressure lower than 2 kPa is reached
5	Documentation	Record at least the manufacturer and serial number and/or the identification of the gas compartment, the reading and the date for further reference
6	Flooding with air	Disconnect the compressor and let the air enter slowly into the gas compartment.
7	Open the gas compartment	Carefully open the gas compartment. Apply safety rules according to 5.1
8	Remove solid by-products and adsorbers when present	Immediately use vacuum cleaner or wipe with a clean lint free rag to collect the solid by-products, if present. Place adsorber materials in a plastic bag. Seal the plastic bag with tape and tag it
9	Neutralisation, if required	If solid by-products were collected, use 10 % by weight soda solution or equivalent to wash and neutralise all parts and then wash with clean water, according to Table 6
NOTE In the case of liquid storage the weight of the storage container is controlled in order to avoid overfilling. The filling factor is smaller than 0,8 kg/l for safety reasons.		

9.2 Recovery and reclaiming from any compartment of controlled and/or closed pressure systems containing heavily arced SF_6

This subclause applies to any compartment of controlled and/or closed pressure systems containing heavily SF_6, when it is recovered for maintenance.

Unless otherwise specified by the original equipment manufacturer in the operating instruction manual, the following detailed sequence of operations for SF_6 recovery from each compartment is performed according to Figure 7. Additional details are in Table 14.

The safety rules given in Clause 5 are strictly followed.



IEC 1217/08

Key

1	Prepare SF_6 handling equipment	9	Open the gas compartment
2	Connect filters	10	Remove solid by-products, adsorber materials and removable parts
3	Connect additional pre-filter	11	Neutralisation
4	SF_6 recovery	12	Documentation
5	Minimise residual SF_6 content	p_p	Initial SF_6 pressure in the gas-filled compartment
6	Documentation	p_a	Atmospheric pressure
7	Flooding with air	p_r	SF_6 residual pressure < 2 kPa
8	Settling down of solid by-products	t_s	Settling down time ≥ 1 h

Figure 7 – Recovering and reclaiming from any compartment of controlled and/or closed pressure systems containing heavily arced SF_6

Table 14 – Recovering and reclaiming from any compartment of controlled and/or closed pressure systems containing heavily arced SF_6

Step		Procedure
1	Prepare SF_6 handling equipment	Check that the SF_6 reclaimer is properly working, the filters and pre-filters are still active and the gas connections are clean and dry, hoses are evacuated and no leaks on connection fittings exist to avoid contamination. Check the validity of the calibration of instruments subject to calibration
2	Connect filters	Connect the pre-filter between the gas-filled compartment and the compressor and the filter between the compressor and the storage container
3	Connect additional pre-filter	Connect an additional pre-filter at the inlet of the SF_6 reclaimer
4	SF_6 recovery	Connect the gas-filled compartment. Use the main compressor stage as soon as the SF_6 residual pressure in the compartment approaches the pressure in the storage container. Use a safety valve and a calibrated gauge. Use an external storage container and avoid its overfilling (see NOTE 1)
5	Minimise residual SF_6 content	Connect the auxiliary compressor stage when the SF_6 residual pressure in the compartment approaches 100 kPa and leave it running until a pressure lower than 2 kPa is reached
6	Documentation	Record at least the manufacturer and serial number and/or the identification of the gas compartment, the reading and the date for further reference
7	Flooding with air	Disconnect the compressor and let the air enter slowly into the gas compartment
8	Settling down of solid by-products	Wait at least for 1 h to give enough time the remaining solid by-products to settle down in the gas compartment
9	Open the gas compartment	Carefully open the gas compartment. Apply safety rules according to Clause 5
10	Remove solid by-products, adsorber materials and removable parts	Immediately use a vacuum cleaner to collect the solid by-products. Place adsorber materials and removable parts in plastic bags. Seal plastic bags with tape and tag them
11	Neutralisation	Use 10 % by weight soda solution or equivalent to wash and neutralise all parts and then wash with clean water, according to Table 6
12	Documentation	Record all relevant information concerning the internal fault. Include some pictures

NOTE 1 In the case of liquid storage the weight of the storage container is controlled in order to avoid overfilling. The filling factor is smaller than 0,8 kg/l for safety reasons.

NOTE 2 In case the gas compartment is open to the atmosphere, the procedure should be followed starting from step 9.

10 Dismantling of SF_6 electric power equipment at the end-of-life

This clause covers the different phases when electric power equipment is dismantled at the end-of-life. From the environmental point of view, this is an important stage in the life cycle of a product.

End-of-life dismantling is performed according to local regulations under the owner/operator’s responsibility and supported by the original equipment manufacturer as his knowledge and experience are essential. Third parties, such as qualified service companies, may also carry out end-of-life dismantling. End-of-life of electric power equipment is considered at the designing stage of state-of-the-art equipment.

NOTE The procedures described in this clause may be also applicable at maintenance and overhaul.

Dismantling of electric power equipment and related treatment of used SF_6, gas compartments, powders, adsorber materials and effluents are conducted with due regard to personnel and environmental safety, as described in Clause 5.

10.1 End-of-life of controlled and/or closed pressure systems

Figure 8 describes the typical procedure to follow during end-of-life of controlled and/or closed pressure systems.

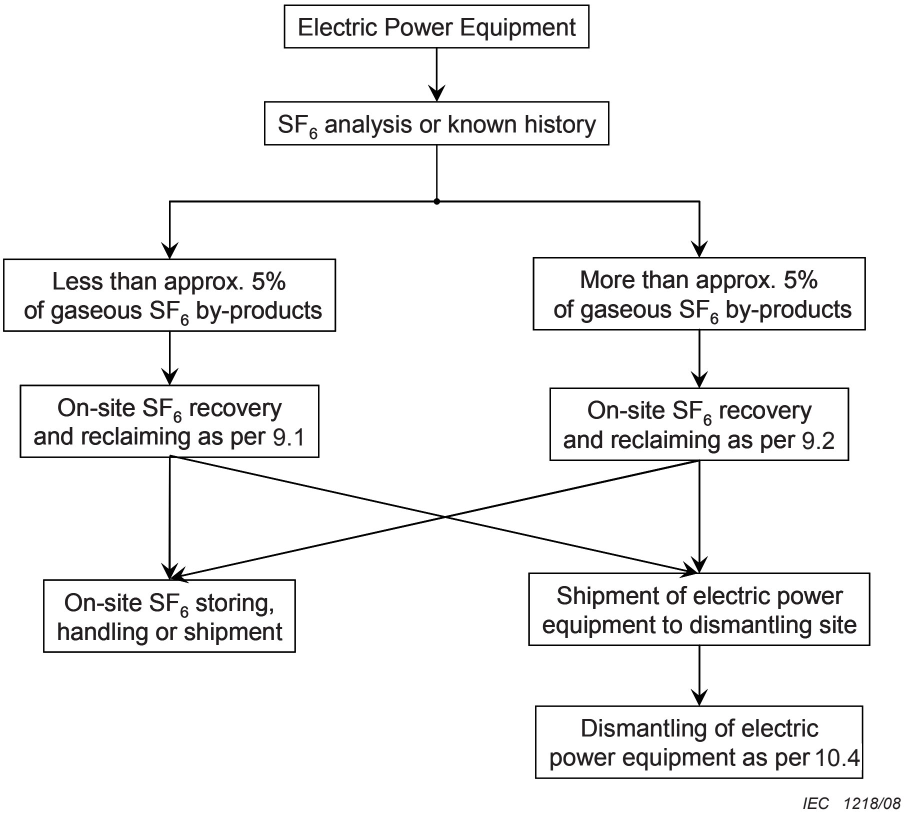


Figure 8 – End-of-life of controlled and/or closed pressure systems

If the past history of a gas-filled compartment is unknown, the gas is analysed and handled in safe conditions according to Clause 9. Once SF_6 has been recovered and reclaimed, it can be either reused on-site, or stored or transported off-site for further reuse, according to Clause 4. The electric power equipment can be either dismantled on-site or shipped to a dismantling site.

10.2 End-of-life of sealed pressure systems

Sealed pressure systems are typically shipped to the dismantling site as shown in Figure 9. If requested, SF_6 recovery and further dismantling could be performed on-site. The procedure for SF_6 recovery remains the same and is reported in 10.3.

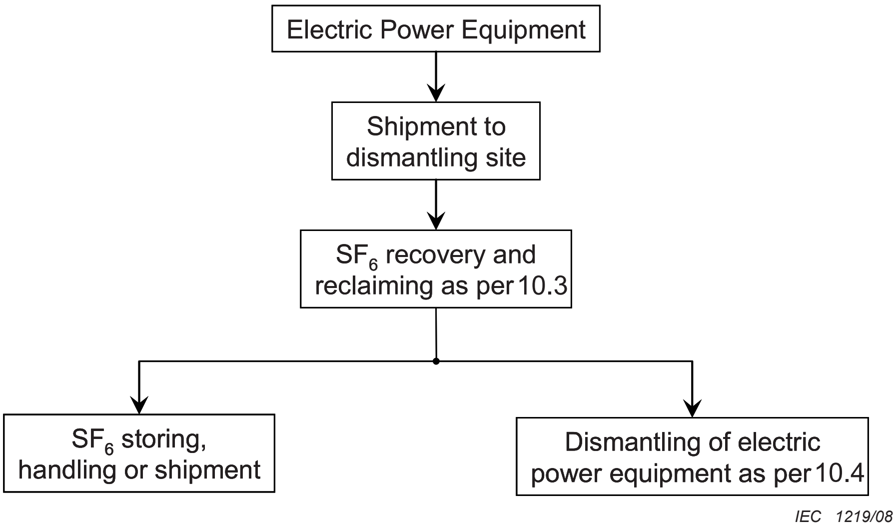


Figure 9 – End-of-life of sealed pressure systems

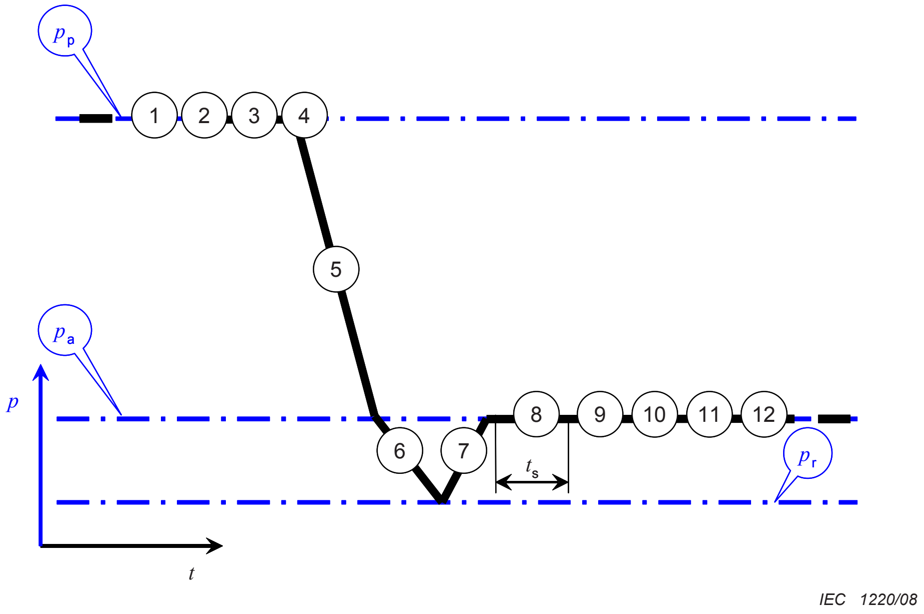
Sealed pressure systems should be shipped to the dismantling site before removal of SF_6, this operation being typically conducted by service companies. These companies implement the necessary handling and storage means to avoid any shocks that may crack or break the enclosure, in particular resin-based enclosures. Experience shows that the risk of the SF_6 being dispersed in the environment during handling and transportation is extremely low, if the transportation instructions issued by the original equipment manufacturer are followed.

10.3 Recovery and reclaiming of SF_6 at the end-of-life of sealed pressure systems

SF_6 recovery and reclaiming at the end-of-life of any sealed pressure systems should be performed at the dismantling site. When sealed pressure systems are fitted with connecting facilities, dedicated tools according to manufacturer instructions should be used for the SF_6 recovery. If not, then tight drilling systems should be used.

Unless otherwise specified by the original equipment manufacturer in the operating instruction manual, the following detailed sequence of operations for SF_6 recovery and reclaiming at the end-of-life of the sealed pressure system is performed according to Figure 10. Additional details are in Table 15.

The safety rules given in Clause 5 are strictly followed.



Key

1	Prepare SF_6 handling equipment	9	Open the gas compartment
2	Connect filters	10	Remove solid by-products, removable parts, and adsorbers when present
3	Connect additional pre-filter, if required	11	Neutralisation, if required
4	Connect SF_6 compartment	12	Documentation
5	SF_6 recovery	p_p	Initial SF_6 pressure in the gas-filled compartment
6	Minimise residual SF_6 content	p_a	Atmospheric pressure
7	Flooding with air	p_r	SF_6 residual pressure < 2 kPa
8	Settling down of solid by-products, if required	t_s	Settling down time ≥ 1 h, if required

Figure 10 – SF_6 recovery and reclaiming at the end-of-life of sealed pressure systems

Table 15 – SF_6 recovery at the end-of-life of sealed pressure systems

Step		Procedure
1	Prepare SF_6 handling equipment	Check that the SF_6 reclaimer is working properly, the filters and pre-filters are still active and the gas connections are clean and dry, hoses are evacuated and no leaks on connection fittings exist to avoid contamination. Check the validity of the calibration of instruments subject to calibration
2	Connect filters	Connect the pre-filter between the gas-filled compartment and the compressor and the filter between the compressor and the storage container
3	Connect additional pre-filter, if required	Connect an additional pre-filter at the inlet of the SF_6 reclaimer
4	Connect SF_6 compartment	Use dedicated tools and follow the instructions of the original equipment manufacturer to connect the SF_6 compartment. In other cases, tight drilling systems are used
5	SF_6 recovery	Use the main compressor stage to transfer the gas to the storage container. Use a safety valve and a calibrated gauge. Use an appropriate external storage container and avoid its overfilling (see NOTE)
6	Minimise residual SF_6 content	Connect the auxiliary compressor stage and leave it running until a pressure lower than 2 kPa is reached
7	Flooding with air	Disconnect the compressor and let the air enter slowly into the gas compartment
8	Settling down of solid by-products, if required.	Wait at least for 1 h to give enough time the remaining solid by-products to settle down in the gas compartment
9	Open the gas compartment	Carefully open the gas compartment. Apply safety rules according to Clause 5
10	Remove solid by-products, removable parts, and adsorbers when present	Immediately use vacuum cleaner or wipe with a clean lint free rag to collect the solid by-products, if present. Place adsorbers and removable parts in a plastic bag. Seal the plastic bags with tape and tag them
11	Neutralisation, if required	If solid by-products were collected, use 10 % by weight soda solution or equivalent to wash and neutralise all parts and then wash with clean water, according to Table 6
12	Documentation	Record at least the manufacturer and serial number and/or the identification of the equipment, the date of dismantling and the quantity of SF_6 recovered in kg
NOTE In the case of liquid storage the weight of the storage container is controlled in order to avoid overfilling. The filling factor is smaller than 0,8 kg/l for safety reasons.		

10.4 Dismantling of electric power equipment at the end-of-life

Figure 11 describes the typical procedure for the dismantling of electric power equipment at the end-of-life.

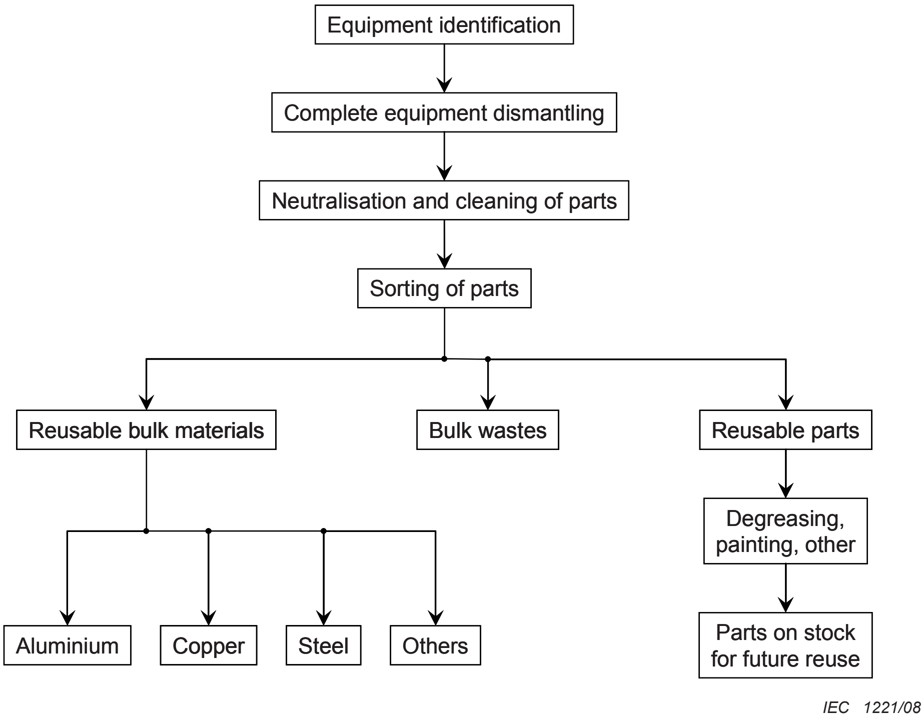


Figure 11 – Dismantling of electric power equipment

The first operation consists in identifying every assembly or sub-assembly coming to the dismantling site. An identification sheet is required with all information necessary for the product.

Gas compartments and internal parts may contain solid by-products, which are neutralised and cleaned so that they can be handled, recycled, or disposed of according to local regulation or international standards. Procedures for neutralisation and cleaning are simple to apply and require only readily available materials, as given in Table 6.

For the dismantling phase, operators should know the products. Tools and drawings should be available.

A typical item of electric power equipment is made up of the following approximate relative quantities of material by weight:

- Metals, ferrous and non-ferrous: 75 % to 90 %
- Dielectric materials: 10 % to 25 %.

Where SF_6 is present, it constitutes only a very small part of the total weight and its presence adds little to the effort required to prepare the equipment for recovery, reuse or disposal. Most of the weight of the dielectric material is provided by solid insulation (for example cast resin, plastics, ceramics). The major part of the reclaimable value is in the metals.

10.5 By-products at the end-of-life

The quantity of by-products within an item of electric power equipment depends on the cumulative arc energy in relation to the amount of SF_6, which has been supplied to it and on the type and quantity of adsorbers. This depends on the function and service history of the equipment in question. A load-break switch is likely to contain much smaller quantities of by-products than a high breaking-capacity circuit-breaker with a history of frequent fault clearances.

Practical examples of calculation of the amount of by-products are given in Annex D. In the large majority of cases, the degree of decomposition, even in circuit-breakers, is low.

The reasons for that are:

- On average, very few high-current interruptions are performed in service.
- Adsorber materials are fitted in gas compartments.

Expected SF_6 characteristics and quantity of by-products for various types of electric power equipment are given in Table 16.

Table 16 – Expected SF_6 characteristics and quantity of by-products

Design	SF_6 characteristics	Expected quantity of by-products
GIS busbars, cable box, vacuum breaker compartment (SF_6 as insulation medium), …	Non arced SF_6	From zero to a few tenths of a percent by volume
GIS earthing switch and disconnector	Normally arced SF_6	Light powder deposit
Medium-voltage load-break switch and ring main unit		Light powder deposit
Medium-voltage and high-voltage circuit-breaker		Up to a few percent by volume, light powder deposits
Any gas-filled compartment after an internal arcing fault	Heavily arced SF_6	Could exceed 5 % by volume, medium to heavy powder deposits

11 Description of SF_6 handling equipment

This clause gives guidelines for the specifications, minimum functionality and performance criteria for SF_6 handling equipment and specific components.

11.1 Reclaimer

The appropriate type and size of the reclaimer should be chosen according to the SF_6 quantity to be handled. Figure 12 shows the basic functional scheme of a general purpose reclaimer. The typical functions of a standard reclaimer are as follows:

- Evacuation of air from the gas compartment
- Filling of SF_6 in the gas compartment
- Recovery of SF_6 from the gas-filled compartment
- Storage and filtering of SF_6
- Flooding of the gas compartment with ambient air.

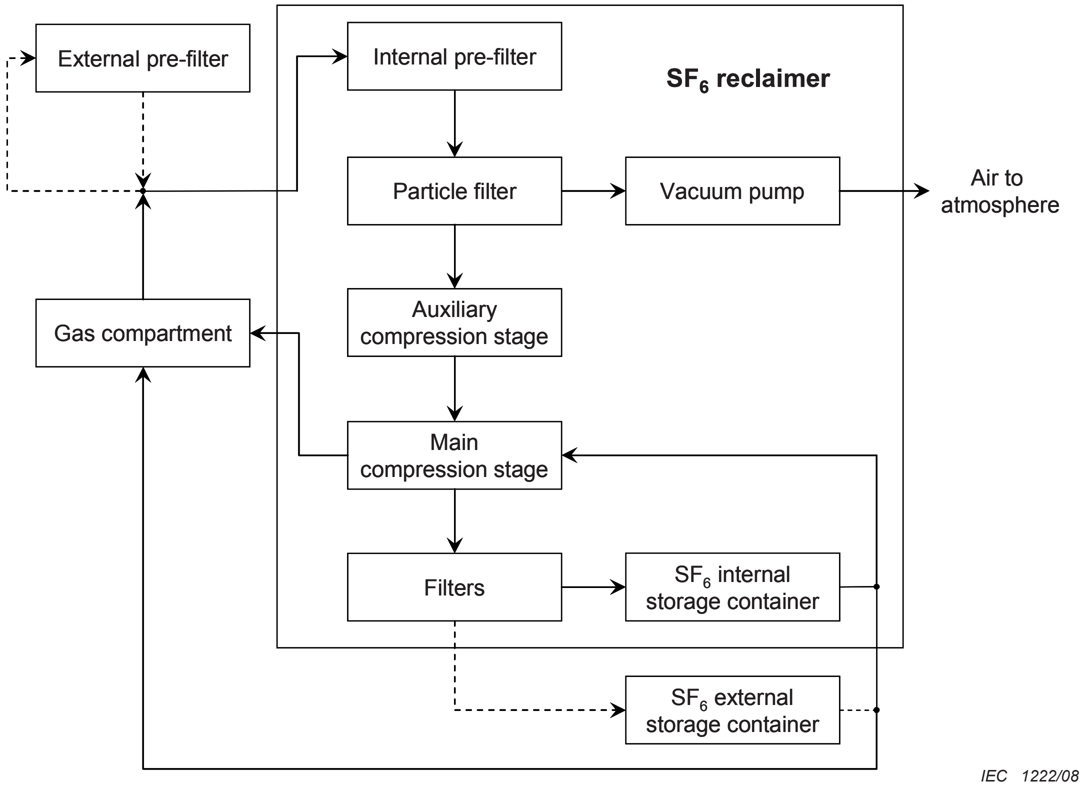


Figure 12 – General purpose reclaimer

11.1.1 External and internal pre-filters

A pre-filter, either external or internal, is required to recover used SF_6. The reactive gaseous by-products are acid compounds and could damage the reclaimer or the gas storage container. The requirements of the pre-filtering unit are basically the same as those of the filtering units installed in the general purpose reclaimer, but the pre–filtering capacity could be considerably higher.

Recommended major characteristics are:

- Pore size lower than 10 µm (low through-flow resistance)
- Residual moisture lower than 200 ppmv
- Residual reactive gaseous by-products lower than 200 ppmv.

11.1.2 Filters

Filters are required to remove the reactive gaseous by-products before they are stored – hence allowing for the reuse of SF_6. These filters are installed in the reclaimer.

Table 17 shows typical filter types used during SF_6 reclaiming.

Table 17 – Typical filter types used during SF_6 reclaiming

Filter Type	Tasks	Major characteristics
Particle filter	Removes solid by-products and other particles at the reclaimer inlet	Pore size lower than 1 µm
Dry filter	Removes reactive gaseous by-products and moisture	Residual moisture lower than 100 ppmv Residual SO_2+SOF_2 lower than 12 ppmv Particle retention ability
Oil filter	Removes oil when required	Special filter utilising active charcoal

11.1.2.1 Particle filter

Some by-products, which are generated during switching operations, are made up of fine solid particles (for example metal particles, solid by-products). The inner side of the particle filter consists of paper or suitable bonded fabric able to retain the particles in a range higher than 1 µm. Normally, the particle filter is installed at the inlet and upstream from the outlet of the reclaimer to protect parts of the reclaimer as well as the gas storage container.

11.1.2.2 Dry filter

Appropriate filters can adsorb moisture and reactive gaseous by-products. They are mainly used in combination with the particle filter. Molecular sieves with a pore size smaller than 0,5 nm are used. In case of a bigger pore size is used, under certain conditions, thermodynamic exothermal reactions can occur resulting in severe filter overheating.

Soda lime ($NaCO_3$) should not be used as a filter material for SF_6 as, upon contact with certain reactive gaseous by-products, produces CO_2, which is difficult to remove from SF_6.

11.1.2.3 Oil filter

An oil trap should be inserted in the SF_6 cycle if an oil-lubricated machine is used or if an oil-insulated electric component is included in the electric power equipment utilising SF_6. The oil removal is achieved in several steps to avoid diffusion of the oil.

NOTE In order to minimize the risk of oil contamination, the use of oil-lubricated equipment is not recommended. Experience has shown that the maintenance and ineffectiveness of the oil separating filters on such equipment make the risk of oil contamination unacceptably high.

11.1.3 Vacuum pump

The vacuum pump is used to evacuate the gas compartment/container/sample cylinders from gases different from SF_6, typically air or N_2 to avoid SF_6 to be mixed with other gases.

The residual pressure at the inlet of the vacuum pump should be lower than 100 Pa. In order to speed up evacuation of gas compartments, the use of vacuum pumps with a residual pressure at the inlet lower than 10 Pa is recommended.

The vacuum pump is equipped with a vacuum pressure gauge. The resolution of the vacuum pressure gauge should be at least lower than 1 kPa (recommended value is lower than 10 Pa. Vacuum gauges independent of the gas type are generally recommended. Thermal vacuum sensors are dependent on the gas type and are not recommended as they react with SF_6 – vapours in different ways giving a false vacuum reading.

A valve is recommended to shut off the connection between the gas compartment and the vacuum pump. The valve should close at least manually (automatically is recommended) after having turned off the vacuum pump to avoid oil diffusion into the gas compartment.

The capacity of the vacuum pump should be suitable for the volume of the gas compartment and the evacuation time. The connecting diameter is also of great importance. For a gas compartment with a volume of 1 000 l, a connecting diameter of 20 mm or ¾ inch is recommended. If smaller diameters are used, the evacuation process is considerably extended and the use of a vacuum pump with a higher capacity is not useful.

11.1.4 Main and auxiliary compressors

When the SF_6 pressure in the gas-filled compartment is higher than the pressure in the storage container, it is quicker to allow direct gas expansion. In all other cases, a compressor is required to recover the gas. As the pressure in the gas-filled compartment may vary within a very wide range, a dual compressor system should be used:

- The main compression, usually employing a piston type compressor, which operates between a gas inlet pressure about 100 kPa (typically higher than 50 kPa) and the pressure in the gas storage container.
- The auxiliary compression, connected in series when needed, operates between the pressure in the gas-filled compartment and the pressure at the inlet of the main compressor.

NOTE 1 Almost all kinds of piston type compressors can be used, however those which are dry-running and hermetically sealed are preferred to reduce the possibility of SF_6 leaks and oil contamination. State-of-the-art compressors can achieve 100 Pa pressure at the inlet.

NOTE 2 A 2,5 MPa rated outlet pressure of the compressor is sufficient to store SF_6 in a gaseous form (5 MPa pressure is recommended). An additional cooling device may be used to speed up SF_6 recovery.

11.1.5 External and internal gas storage containers

Commercial pressure vessels or special storage containers for used SF_6 are available as gas storage containers. They are mobile, stationary or installed in the reclaimer. Only specially approved containers for storage and/or transportation of used SF_6 are allowed. The maximum pressure of the storage container should be suitable for the final pressure of the compressor. The local regulations for the operation of pressure vessels are observed. For storage containers with liquid SF_6 storage a nominal pressure of 5 MPa is used.

11.1.6 Evaporator and gas storage container heater

If SF_6 is stored in liquid form and used as a gas, icing or frosting of the gas storage containers takes place when large gas quantities are handled in a short time. The evaporator receives liquid SF_6 from the gas storage container and is designed so that no liquid can reach the gas compartment.

The gas storage container heaters are designed to avoid accidental overheating and not exceeding 60 °C gas temperature.

11.1.7 Gas piping and pipe junctions

Gas piping and pipe junctions should be designed to avoid leaks and corrosion. For that purpose, copper and brass or stainless steel can be used. The design of both piping and junctions should take vibration into account so that periodical operations such as re-tightening of fittings are not required.

11.1.8 Control instruments

Control gauges should be provided to show the gas pressure in the gas-filled compartment, the vacuum level, the gas temperature, etc. They should be placed in a position so that they can be observed when initiating operations of the general purpose reclaimer. Accuracy and resolution of the gauges should be adequate to allow preservation of safe operating conditions.

11.1.9 Safety valves

Safety valves are used in the SF_6 cycle for pressure relief. Local safety regulations are followed. Safety valves, which do not directly release SF_6 to the atmosphere, should be used.

11.2 Flexible hose connections

The reclaimer, the gas storage container and the gas compartment are connected via flexible hose connections. Particular care should be exercised to avoid the presence of air or other compounds inside the hoses in order to reduce the possibility of contaminating the gas. For this reason, hose connections with both self-closing and vacuum tight couplings are required. Suitable hoses, typically made of PTFE (polytetrafluorethylene or Teflon) or flexible stainless steel, able to withstand vacuum and permeation are required.

11.3 Portable devices for gas measurement

Table 18 gives a survey on the gas measuring devices including recommended measuring range and minimum accuracy.

Table 18 – Gas measuring devices

Device	Measurement	Range	Minimum accuracy
Dew point meter	Moisture	Dew point: -50 to 0 °C	±2 °C
SF_6 percentage measuring	SF_6 percentage SF_6/N_2 or SF_6/air	0 to 100 % by volume	±1 % by volume
Analysers of reactive gaseous by-products	By-products as for example SO_2 Oil mist	1 to 25 ppmv 0,16 to 1,6 ppmv	±15 % of the full range
SF_6 pressure gauge	Pressure	0 to 1 MPa	±10 kPa
Thermometer	Temperature	-25 to 70 °C	±1 °C

The gas temperature should be taken into account for a comparison at the reference temperature of 20 °C.

Gas quality measurements can be made under laboratory conditions and on-site. The following subclauses describe the most commonly portable instruments used on-site for the measurement of:

- The moisture content in the gas;
- The SF_6 percentage/quantity of inert gases;
- The residual quantity of reactive gaseous by-products/residual acidity content.

However some other instruments based on new technologies are available on the market and allow for combined determination of multiple gas characteristics.

11.3.1 Dew point meter

The moisture content can be measured with different measuring principles and measuring instruments. However a dew point meter is the most common portable instrument used on purpose. The instrument measures the dew point of the gas, expressed in °C, and may convert it into relative mass concentration, expressed in mg/kg.

Desirable characteristics are:

- Sensor resistant to oil traces and corrosive gases;

- Permeation resistant connecting pipes using self-sealing valve connections;
- Calibrated or capable of field calibration;
- No SF_6 gas release to the environment (for example small compressor for gas refilling or make use of an empty cylinder);
- Less than 6 g gas used per measurement;
- Average time to obtain the readout less than 5 min.

11.3.2 SF_6 percentage measuring device

Devices that compare the speed of sound or the thermal conductivity of the SF_6 gas mixture with pure SF_6 are used to determine the SF_6 percentage. Velocity of sound based systems are fast (response time less than 1 min), accurate to ±1 % by vol., do not need recalibration and use only a minimal amount of gas. Their readout is the SF_6 concentration expressed in % by volume. They are mostly calibrated for mixtures of SF_6 and nitrogen and/or air.

Desirable characteristics are:

- No SF_6 gas release to the environment (for example small compressor for gas refilling or make use of an empty cylinder);
- Less than 3 g gas used per measurement.

Devices measuring the concentration of the non-reactive gases (such as oxygen sensors) and then calculating the % by vol. of SF_6 should not be used as different non-reactive gases such as nitrogen or CF_4 may be present.

11.3.3 Reaction tubes sensitive to SO_2

Reaction tubes change their initial colour if SF_6 containing SO_2 is fed through them. SO_2 reaction tubes are also sensitive to SOF_2. A small amount of SF_6 from the equipment (~6 g) is needed. That gas sample flows through the reaction tube to perform the measurement. It is expressed in µl/l. A measuring range from 0 to 25 ppmv is recommended.

Desirable characteristics are:

- Calibration for SO_2 and SOF_2;
- Connecting pipes resistant to reactive gaseous by-products and utilising self sealing valve connections;
- No SF_6 gas release to the environment (for example small compressor for gas refilling or make use of an empty cylinder);
- Less than ~6 g gas used per measurement

Reaction tubes sensitive to HF should not be used, as this gas reacts quickly with all metals to form metal fluorides.

11.3.4 Portable SF_6 detectors

Portable detectors for SF_6 are broadly of two types:

a) Electron capture detector using a ß-particle source to ionise a pumped sample. The ion current between electrodes is measured. An inert gas carrier is usually used. This type is much more expensive and considerably less portable than type b). Sensitivities down to 0,1 ppmv of SF_6 in air can be achieved.

b) Corona discharge cell using a high-voltage (1 kV to 2 kV) applied to a point-plane electrode configuration. The discharge current is measured. This type of detector is used in a variety of highly portable, battery-powered units of relatively low cost. Sensitivities of below 10 ppmv can be achieved, but not with all available units [7].

Detectors of the first type are generally used for leak tracing and quantification.

Detectors of the second type, if sufficiently sensitive, could be suitable for assessing whether an area contains SF_6 and can be useful for leak detection.

11.3.5 Alarm system SF_6 detectors

Alarm systems require detectors with very high long-term stability. The infrared absorption characteristic of SF_6 is used as the basis for most detectors of this type [8]. An infrared source is used to heat a gas sample in a differential pressure-measuring device using a sensitive capacitance transducer. The pressure rise is measured.

Sensitivities down to 10 ppmv can be achieved. Automatic calibration facilities may be incorporated. In some installations, samples of air are piped from various points to a central detector. The active detection point can be selected automatically or manually.

Alarm systems incorporating SF_6 detectors are generally used only where very large volumes of SF_6 are contained in equipment housed indoors, such as in high-voltage GIS installations.

11.4 Cylinder for gas samples

Stainless steel cylinders with a volume smaller than 1 litre are recommended. The gas quantity should be not smaller than 6 g. The gas should be sampled directly from the container (for example gas-filled compartment, gas storage container of the reclaimer) using suitable fittings. If the pressure in the gas container exceeds the maximum allowable pressure of the cylinder, then a pressure regulator and a pressure gauge are used.

Annex A
(informative)

Sulphur hexafluoride

A.1 Introduction

Sulphur hexafluoride (SF_6) is a synthetic gas formed by 6 atoms of fluorine gathered around a centrally situated atom of sulphur. The chemical bond between fluorine and sulphur is known as one of the most stable existing atomic bonds. Six of them grant the molecule very high chemical and thermal stability.

SF_6 is strongly electronegative (i.e. it tends to attract free electrons). It has a unique combination of physical properties: high dielectric strength (about 3 times that of air), high thermal interruption capabilities (about 10 times that of air) and high heat transfer performance (about twice that of air).

For that reason, since the early 1960's, SF_6 has been successfully used by the Electricity Industry in power equipment for the high-voltage transmission and distribution of electricity (for example high-voltage and medium-voltage switchgear, gas insulated substations, ring main units, circuit-breakers, transformers, cables).

Other non-electrical industrial applications include: aluminium production, magnesium casting, semiconductor production, production of flat panel screens, nuclear fuel cycle, noise insulating windows, tires, high performance radar, tracer gas for meteorological measurements and in power plant piping, and military applications.

A.2 Chemical properties

Pure SF_6 is odourless, tasteless, colourless, non-toxic, non-flammable, very stable and inert. Its solubility in water is 4 times lower than that of air. Its compatibility with materials used in electric constructions is similar to that of nitrogen, up to temperatures of about 180 °C.

Table A.1 lists the main chemical characteristics.

Table A.1 – Main chemical characteristics of SF_6 [9]

Formula	SF_6
CAS Number	2551-62-4
Molecular weight	146,05 g/mol
Sulphur content	21,95 %
Fluorine content	78,05 %
Molecular structure	Octahedral with fluorine atoms at the six corners
Bonds	Covalent
Collision cross-section	0,477 nm
Decomposition temperature in quartz container	500 °C

A.3 Physical properties

SF_6 is one of the heaviest known gases: in normal conditions it is about five times heavier than air.

The mixing with air by convection and diffusion is slow, but once it has mixed it does not separate again.

The thermal conductivity of SF_6 is lower than that of air, the overall heat transfer properties are two to five times better due to its lower viscosity and higher density.

In electric power equipment the normal pressure range of SF_6 is between 0,1 MPa and 0,9 MPa absolute. The pressure/temperature/density characteristics of the gas are shown in Figure A.1.

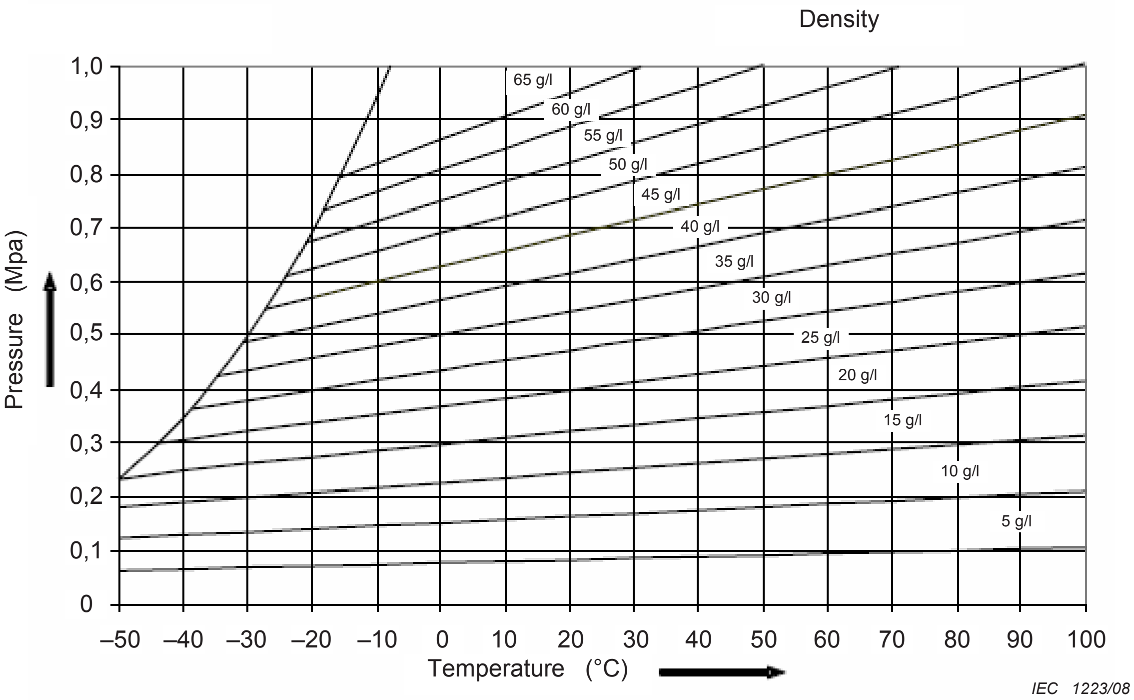


Figure A.1 – Pressure/temperature/density characteristics for SF_6 [9]

Table A.2 lists the main physical characteristics.

Table A.2 – Main physical characteristics of SF_6 [9]

Density at 20 °C 100 kPa	6,07 kg/m^3
Thermal conductivity at 25 °C 100 kPa	0,013 W/(m.K)
Critical temperature	45,58 °C
Critical pressure	3,759 MPa
Critical density	740 kg/m^3
Solubility in water at 20 °C	6,31 cm^3 SF_6/kg H_2O
Sound velocity at 0 °C 100 kPa	129,06 m/s
Refractive index	1,000783
Heat of formation	-1221,58±1,0 kJ/mol
Entropy of reaction	-349,01 J/(mol.K)
Specific heat at constant pressure at 20 °C 100 kPa	96,60 J/(mol.K)
Equation of state	See Figure A.1

A.4 Electrical properties

The excellent dielectric properties of SF_6 are due to the strong electronegative character of its molecule. It has a pronounced tendency to bind free electrons forming heavy ions with low mobility making the development of electron avalanches very difficult.

The electric strength of SF_6 is about 3 times higher than that of air under the same conditions.

Because of its low dissociation temperature and high dissociation energy, SF_6 is an excellent arc quenching medium.

When an electric arc cools in SF_6, it remains conductive to a relatively low temperature, thus minimising current chopping before current zero, and thereby avoiding high overvoltages.

Table A.3 lists the main electrical characteristics of SF_6.

Table A.3 – Main electrical characteristics of SF_6 [9]

Critical breakdown field relative to pressure	89 V/(m.Pa)
Relative dielectrical constant at 25 °C and 0,1 MPa absolute	1,00204
Loss factor (tan δ) at 25 °C and 0,1 MPa absolute	<2,0 × 10^{-7}
Effective ionisation coefficient	$\frac{\alpha}{p} = A\frac{E}{p} - B$ α: m^{-1} E: V/m p: Pa A: 2,8 × 10^{-2}/V B: 89 V/(m.Pa)

A.5 Handling, hazards and health characteristics

SF_6 does not support combustion. As the gas is much heavier than air, under conditions of insufficient mixing with air the gas has a tendency to accumulate at low levels. Areas below ground level, poorly ventilated or unventilated areas (for example cable ducts, trenches, inspection pits, drainage systems), may remain full of SF_6. Personnel should be aware of the danger of asphyxiation in such places. Equipment containing SF_6 should not be entered without adequate ventilation and personal protection tools.

SF_6 is non-toxic and biologically inert. According to the American Conference of Governmental Industrial Hygienists (ACGIH) the Threshold Limit Value (TLV) in terms of Time Weighted Average (TWA) is 1 000 ppmv (6 100 mg/m^3). This is intended for places of work in which personnel spend up to 8 h per day, 5 days per week [10]. That TLV is normally adopted for all harmless gases not present in the atmosphere.

SF_6 does not harm the life or the ecosystem but it is a potent and persistent greenhouse gas, as described in Annex B.

When handling SF_6 it is necessary therefore to adopt procedures to keep the gas in a closed cycle, avoiding any deliberate release to the environment.

Technical grade SF_6 is commercially available, according to IEC 60376.

Used SF_6 can be reused on-site, according to IEC 60480.

Used SF_6 can be reused at the gas manufacturer, according to the specification given by the gas manufacturer. In case the gas does not comply with the specification, it is disposed according to local or international regulations on waste management.

Annex B
(informative)

Environmental effects of SF_6

B.1 Introduction

Every human activity has an effect on the environment; the impact of a particular activity depends on its scale and on the materials involved. Activities where gases are produced or used may cause releases to the atmosphere. Three major aspects are considered:

- Ecotoxicology: toxic material and gases with effects on the environment and all forms of life.
- Ozone depletion: increase in dimensions of the holes in the stratospheric ozone layer.
- Global warming/climate change: increase in the greenhouse effect.

B.2 Ecotoxicology

SF_6 is not toxic and has no reported potential to be acute or chronic ecotoxic. As its solubility in water is very low, it presents no danger to surface and ground water or the soil. A biological accumulation in the nutrition cycle does not occur. Therefore, SF_6 does not harm the ecosystem. SF_6 is:

– not carcinogenic: not causing cancer;

– not mutagenic: not causing damage to the genetic constitution;

– not nitrifying: no enrichment in the food chain;

– low soluble in water.

B.3 Ozone depletion

SF_6 and its by-products from application in electric power equipment do not contribute to the destruction of stratospheric ozone layer [9] because they do not contain either chlorine or bromine.

B.4 Global warming/climate change (greenhouse effect)

The average global temperature of the earth results from a balance between the heating effects of solar radiation and the cooling associated with the infrared radiation from the earth. Some of the infrared radiation is reflected back to the surface of the earth and the greenhouse effect is a natural phenomenon that contributes to allow the life on earth.

It is due to the natural greenhouse gases (mainly moisture, carbon dioxide, methane) which are transparent to the radiation coming from the sun, but absorb the infrared radiation reflected back from the earth.

Without the greenhouse gases the heat from the sun would be radiated back into space and the temperature of the earth would be much lower.

The presence of the greenhouse gases traps some solar energy in the atmosphere. The consequence is a higher average temperature of the planet compared with the temperature that would have prevailed if no greenhouse effect had existed. Scientific estimations evaluate the increase to as much as 33 ºC (from –18 ºC to the actual 15 ºC) [11].

Today, the natural phenomenon is by far predominant and human activities give only a small contribution to the total greenhouse effect. However, as the human contribution is growing, this is today a major concern. According to several studies, the actual trend, if not reversed, will cause a significant increase of the average temperature of the planet: the global climate will be changed.

Both manmade and natural greenhouse gases contribute to the greenhouse effect. The Kyoto Protocol [13] is an international agreement to control the emission of manmade greenhouse gases.

The basket of greenhouse gases, to be monitored according to the Kyoto Protocol is composed of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). The latter three substances are fluorinated greenhouse gases (or F-gases).

The concentrations of different gases relevant to the environment including those in the Kyoto Protocol are regularly monitored by several scientific bodies. In particular the Intergovernmental Panel on Climate Change (IPCC) prepares periodically assessment reports, up-dating the existing information on emissions and evaluating their potential future impact on the environment according to different hypothesis of their emission trends. The latest published is the Third Assessment Report (TAR) in October 2001 [11].

The fourth Assessment Report is due by the end of 2007. IPCC was established by the World Meteorological Organisation (WMO) and the United Nations Environmental Programme (UNEP) in 1988. F-gases are known for their high global warming impact as compared to CO_2, the main originator of the global warming effect, and contribute approximately in the measure of 1,5 % to the overall greenhouse gas effect. The strong infrared absorption of SF_6 and its long lifetime in the environment are the reasons for its high Global Warming Potential (GWP) which is 22 200 higher than CO_2, according to the Third Assessment Report. The GWP is calculated over a time period of 100-years warming potential of 1 kg of a gas referred to 1 kg of CO_2. Its overall contribution to the global greenhouse gas effect from all applications amounts to approximately 0,2 % overall.

However, the GWP of SF_6 alone is not adequate to measure the environmental impact of electric power equipment based on SF_6 technology. The environmental impact of any specific application should be evaluated and/or compared using the Life Cycle Assessment – LCA approach as regulated by ISO 14040 [14].

The Electric Industry utilises SF_6 in a closed cycle, banking it for example in gas insulated substations (GIS), medium-voltage and high-voltage gas circuit breakers (GCB), high-voltage gas insulated lines (GIL), gas insulated voltage transformers (GVT). In Asia, significant quantities of SF_6 are banked in gas insulated power transformers (GIT) as well.

In spite of being reported as the most important user of SF_6 worldwide, the Electric Industry is a low contributor to the global emission of SF_6, far below to other industries or users with “open application” of the gas. However, its importance as source substantially varies from region to region and from country to country, depending on the SF_6 handling procedures adopted, the tightness of the electric power equipment and the amount of gas banked in electric equipment.

Regional average emission rates presently vary between far less than 1 % to more than 10 %. In general, emission rates have declined significantly since 1995. Targeted industry actions have reduced emissions by 50 % to 90 % in Europe [15], Asia [16], and North America [17] and [18]. Those actions include:

- designing equipment requiring a smaller quantity of SF_6 and having a high tightness degree;
- improving handling processes and handling equipment for all life cycle stages according to the present technical report.

B.5 By-products

Major failures causing gas releases are extremely rare as records from 40 years of experience show. The quantities released in such extreme cases are again very limited by the fact that standard design of products is compartmented, limiting the fault to the place where it originates. The gas quantities concerned are subsequently small fractions of the total gas banked in a substation.

Annex C shows that by-products can be converted without difficulty into neutral products available in nature. Procedures for their treatment, handling and disposal ensure that they have a negligible impact on the environment.

B.6 Environmental compatible SF_6 policy

SF_6 should be handled in a closed cycle, to avoid any deliberate release to the environment. Among all the voluntary initiatives, gas recovery and reuse have the highest priority.

Voluntary agreements [19] involving manufacturers and users have been signed in some countries with the aim of controlling and reducing emissions of SF_6 from the electric power equipment. In general, in such agreements, environmental compatible policies mention that for the development, manufacturing, installation, operation, maintenance and end-of-life disposal of electric power equipment utilising SF_6, state-of-the-art technologies and procedures are applied to minimize SF_6 emissions.

Annex C
(informative)

SF_6 by-products

C.1 Decomposition of SF_6

When arcing occurs in SF_6 due either to normal switching operations or fault clearances, or in the unlikely event of an internal arcing fault, different by-products are generated simultaneously in varying quantities [5], and [9]. When the SF_6 molecule is stressed by temperature, radiation or electrical discharge and separation of fluorine atoms occurs, a number of radicals, ions, or neutral molecules are produced, depending on the type of excitation and the energy input, according to:

$$SF_6 \xrightarrow{\Delta E} SF_x + (6\text{-}x)F,\ 0 < x < 6 \qquad (C.1)$$

When the input of energy ΔE ceases, most of the atoms recombine to form SF_6, whilst others combine with different substances in the system to form a variety of stable end products. Such substances include in particular oxygen and water and also materials used in the construction of the equipment.

These by-products are considered here in relation to the energy delivered to the SF_6.

C.1.1 Behaviour of SF_6 in an electric arc

Heavy current arcing occurs normally during circuit breaker switching and fault clearance operations, and abnormally during an internal arc fault.

From temperatures of 500 °C, SF_6 begins to decompose into its constituent parts, with the degree of decomposition being directly proportional to the quantity of energy converted. In the dissociation process defined in equation (C.1), the SF_6 molecules are broken down into sulphur and fluorine atoms at about 3 000 °C.

The large quantity of heat adsorbed during this process is dissipated away from the arc zone by radiation and convection. Below a temperature of about 1 000 °C, the atoms recombine or react with other substances, such as vaporised electrode metal, the vessel wall, plastics or impurities. Gaseous and solid by-products can arise, including metal fluorides and sulphur fluorides, of which the most important are CuF_2, AlF_3, WF_6, CF_4 and SF_4.

These products, generally known as primary by-products, are formed during or shortly after a discharge in the less-than-one-second range. Dust-like deposits which may appear on the surfaces of insulators during normal operation have no detrimental effect on their dielectric performance.

Some of the by-products are chemically stable; others are very unstable, particularly in presence of water.

In presence of oxygen, by-products can arise as follows:

$$S + O + 2F \longrightarrow SOF_2 \qquad (C.2)$$

$$SF_4 + O \longrightarrow SOF_2 + 2F \qquad (C.3)$$

$$SF_3 + O \longrightarrow SOF_2 + F \qquad (C.4)$$

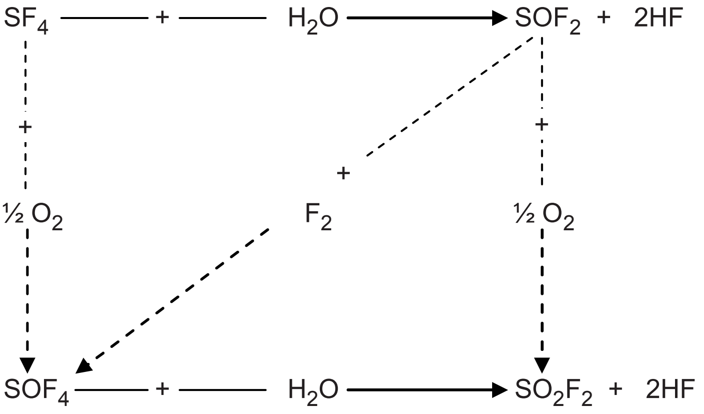
$$SF_5 + O \longrightarrow SOF_4 + F \qquad (C.5)$$

The oxygen involved in the reactions (C.2), (C.3), (C.4), and (C.5) may remain as result of the evacuation process or may be released by the electrode materials during arcing. SOF_2 is the major by-product.

In the presence of moisture, the following reactions occur:

$$F + H_2O \longrightarrow HF + OH \qquad (C.6)$$

$$SF_5 + OH \longrightarrow SOF_4 + HF \qquad (C.7)$$



(8)

The dashed lines in (C.8) indicate reactions that occur only to a limited degree during SF_6 decomposition in an arc. Whilst the reactions of (C.8) imply the formation of significant quantities of HF, this product has not been reported in large quantities following power arcing in electric power equipment. This is probably because by-product formation is mainly according to (C.2), (C.3) and (C.4). It is also possible that HF formed by the reactions of (C.8) further reacts with metal vapours to produce metal fluorides.

SF_4 is produced in significant quantities but hydrolyses rapidly (C.8) in the presence of moisture.

In the continued presence of moisture, further hydrolysis occurs, leading to:

$$SOF_2 + H_2O \longrightarrow SO_2 + 2HF \qquad (C.9)$$

Other reactions have been reported in the literature; additional by-products of arcing such as S_2F_{10} may be formed. However, the quantity of S_2F_{10} formed under arcing conditions is extremely low, because SF_5 radicals, produced at high temperatures, form S_2F_{10} only when cooled very rapidly, a condition not likely to apply in the arc [20].

C.1.2 SF_6 decomposition with low current discharges

Whilst operating voltage is applied to equipment containing SF_6, the possibility of low current discharges such as corona, sparking and partial discharges cannot be ruled out. However, the concentrations of by-products resulting from such discharges are likely to be very low. When SF_6 is decomposed in spark discharges, the reactions shown in dashed lines in (C.8) will predominate [20].

C.1.3 Catalytic decomposition of SF_6 (high-temperature behaviour)

SF_6 can be heated to 500 °C in quartz vessels without decomposing. Up to temperatures of about 150 °C, all commonly used materials, such as metals, glass, ceramics, rubber and polyester resin are fully resistant to SF_6. It is only at temperatures higher than 200 °C that some metals begin to have a decomposing effect on the gas, but in the case of the metals and alloys normally used, this effect is not observed to any marked degree until the temperature range of 400 °C to 600 °C is reached [9].

As the maximum operating temperatures inside electric power equipment in the absence of arcing are far below these values, no SF_6 decomposition of this kind is to be expected during operation.

C.2 Corrosion behaviour of SF_6 and its by-products

SF_6 is a completely non-reactive gas. There is no possibility therefore that corrosion will be caused directly by the SF_6 itself. However, the primary and secondary by-products, in presence of moisture, may form corrosive electrolytes which may lead to damage some of the material used inside the equipment.

The metals commonly used, such as aluminium, steel, copper and brass, are hardly attacked at all, but materials such as glass, porcelain, insulation paper and the like are more vulnerable to damage, depending upon the concentration of the corrosive substances concerned. Other insulating materials, such as epoxy resin, polyester, polyethylene, polymethylene oxide, PTFE, PVC, etc., are not significantly affected.

It is important that measures be taken in the design to take account of the corrosive properties of the by-products. Corrosion can be prevented by the thorough exclusion of moisture and by using suitable materials.

C.3 Measures for the removal of by-products

Moisture and by-products inside equipment in service can be reduced to acceptable levels by adsorption. Materials such as alumina, molecular sieves or mixtures thereof are suitable for this purpose. They adsorb the gaseous reactive by-products very effectively and practically irreversibly, and at the same time ensure that the gas maintains a low dew point [9].

Disposal of by-products removed from equipment is straightforward. The acid components (sulphuric acid and hydrogen fluoride) are degraded by means of alkaline compounds.

Most of the solid reaction products are not soluble in water, or can be dissolved only with difficulty, but certain metal fluorides can react with water to form hydrofluoric acid. It is necessary therefore to treat the solid reaction products with calcium hydroxide (lime), for example, to neutralise the acid components. The resultant sludge can then be disposed of according to local regulations.

C.4 Physiological characteristics of by-products

By-products can cause irritation of the skin, eyes and mucous membranes, such as in the respiratory tract, and in high concentrations can cause pulmonary oedema, given sufficient time of exposure.

SF_6 containing by-products has an unpleasant pungent smell that in itself is associated with an irritant effect. The olfactory thresholds, especially for SOF_2, SO_2 and HF, are of the same order as the TLVs. Because of these characteristics, even small quantities of gaseous by-products may give rise to unmistakable warning indications within a matter of seconds, before any risk of poisoning can arise [5].

Annex D
(informative)

Potential effects on health of SF_6 by-products

D.1 Introduction

This annex examines the risks to health due to SF_6 accidentally released into the local atmosphere by leakage and in the event of an internal fault.

During normal service SF_6 remains inside the electric power equipment and the by-products formed are neutralised by molecular sieves as well as by natural recombination processes. SF_6 can become present in the atmosphere because of leakage or if a gas-filled compartment fails to contain the gas, for example in the unlikely case of an internal fault. It is necessary to differentiate clearly between leakage conditions and internal fault situations leading to a sudden release of SF_6, when evaluating health risk.

In the case of leakage it is necessary to consider the effects of long-term exposure to the gaseous by-products. The concentrations of these products in the air should remain low enough to present no threat to unprotected personnel during a normal working period of, for example, 8 h.

In the case of a sudden release of SF_6 due to an internal fault, mandatory evacuation and ventilation procedures imply a momentary exposure. By-product concentrations of higher levels than would be tolerable during, for example, 8 h can be tolerated if the exposure time is considerably reduced. Clearly in this case account should be taken of all possible sources of toxic emanations and this requires detailed knowledge of all of the products formed. In this respect a full treatment should consider contributions from metal vapour, burnt plastics, cable insulation, paint, etc., on an equal footing to those attributable to the SF_6.

NOTE For example, by comparison of long-term exposure limits, copper fumes from vaporised electrodes are about four times as toxic as arc-decomposed SF_6 (SOF_2) whilst aluminium fumes are about four times less. Both can be produced in large quantities in any incident where electrical arcing occurs, regardless of the insulation medium employed, and may constitute the major risk to health (see D.4.7.2). The contribution of fumes from the combustion of plastics (see D.4.7.3) is also highly significant.

The first aim of this annex is to lay out the basic guidelines for estimating the concentrations of toxic by-products in the air in an environment into which SF_6 has been released. The effects of other potentially toxic substances released under fault conditions are also considered.

The following subclauses give the methods for calculating the risks associated with the presence of by-products in the atmosphere due to leakage and to internal fault together with the principles adopted for performing the calculations.

D.2 Overview

Methods are presented for calculating the risk associated with the presence of by-products in the atmosphere due to leakage and to internal fault. The principles adopted for performing the calculations are presented in the following clauses.

D.3 Formation and health effects of by-products

D.3.1 Formation of by-products

During high power arcing in SF_6 the arc core reaches temperatures of the order of 10 000 K. At these temperatures the molecules of the gas are completely broken down into their parent atoms, sulphur and fluorine, as reported in C.1.1. Any impurities present, such as air or moisture, are dissociated in a similar manner. The result of this is a localised region containing only single atoms of sulphur, fluorine, hydrogen, nitrogen, oxygen and diverse ions. The heating of the electrodes by the arc roots adds vapours of copper, tungsten, graphite and/or aluminium to this atmosphere.

After arc extinction or in regions where cooling commences, these atoms start to bind together again and reform mainly SF_6. However, chemical reactions take place with the impurities present and in particular with moisture and oxygen, giving rise to the so-called arc by-products, as reported in Annex C. The quantities formed are directly related to the electrical discharge energy.

The most frequently encountered by-products are: SOF_2, SO_2, HF and also CF_4, SF_4 and SO_2F_2 [21]. The existence of these by-products is of importance only if they enter the local atmosphere. Their concentrations inside the electric power equipment are of no direct significance, especially since the presence of adsorbers (such as molecular sieves) will tend to purify the gas.

For some time there were concerns that the highly toxic gaseous by-product S_2F_{10} might constitute a major contributor to the toxicity of SF_6 in which arcing has occurred. However experiments later performed showed that this idea is not substantiated [22]. In fact S_2F_{10} appears now to be formed in such extremely small quantities during arcing as to contribute negligibly to the overall toxicity of SF_6.

It is also known that S_2F_{10} is formed by low-energy electrical discharges in SF_6 and that under these conditions, higher S_2F_{10} production rates are encountered [23] than during arcing. The high toxicity of this compound, at concentrations that until recently were difficult to detect, has prompted considerable investment in research into the potential risks associated with its presence [20]. However, S_2F_{10} decays in the presence of moisture [23], at temperatures exceeding 200 °C, and at ambient temperature by catalytic wall decomposition. The last mechanism is so efficient that the S_2F_{10} generated in equipment is reduced to a negligible quantity [24].

D.3.2 Effects of by-products on health

If SF_6, which has been subjected to arcing or to low-energy discharges, is exhausted into the work place then the potential health risk will depend on the concentration of each by-product in the air, and hence on the volume of the room containing the equipment. Toxicity estimations should take account of the concentration of each component present in terms of the permissible concentrations for appropriate exposure times.

D.3.2.1 Health effects of arc decomposed SF_6

For multi-component mixtures, toxicologists define three general cases:

- each component acts in a different manner, or on different target organs; the effects are hence not cumulative and each component is treated separately;
- the components act in a similar manner on the same target organs; their effect is thus cumulative and calculations will take this into account;
- one component largely outweighs the contribution of the others; the overall toxic effect can be estimated by studying the concentration of this component alone.

A survey of the majority of work carried out over the past decades on high power arc decomposition of SF_6 [21] and [25] allows the following conclusion to be drawn: the toxicity of arc decomposed SF_6 is initially dominated by one specific compounds, the gas thionyl fluoride SOF_2.

This conclusion justifies the adoption of the following: the overall health risk to personnel, due to arc decomposed SF_6, should be estimated using the SOF_2 concentrations generated.

In this report the by-product SOF_2 is used as the indicator of the overall toxic effect of arc decomposed SF_6. This allows the health risk in various situations to be assessed together with the implications to safety procedures.

Hydrolysis of the SOF_2 may occur in the presence of significant concentrations of moisture, producing SO_2 and HF, as reported in C.1.1. The risks of exposure to such a mixture, neglecting that HF is unlikely to remain in the atmosphere for long periods because of its high reactivity, are slightly higher than for SOF_2, as detailed in D.4.5.1. This is taken into consideration when assessing the risks due to leakage, where sufficient time may elapse for the hydrolysis reaction to occur, either inside the equipment or in the atmosphere. Hydrolysis of SOF_2 may be neglected for internal fault situations where the time between the fault and subsequent ventilation and repair work is short.

D.3.2.2 Health effects of SF_6 decomposed by low-energy discharges

During low-energy discharges, the by-product S_2F_{10} may be formed in very small quantities. It is the most toxic by-product of SF_6 known; for this reason it is also considered in the assessment of the risks due to leakage from high-voltage equipment. The contributions to toxicity of other by-products such as SOF_2, SO_2 and HF are negligible in SF_6 which has been decomposed by low-energy discharges, so these products are not considered.

D.3.2.3 Exposure duration and dilution in air

The two key notions essential to any evaluation of risk to health due to toxic substances are:

- Dilution into the surrounding volume
- Time duration of exposure.

The first notion is required to enable the conversion from the concentration of by-products formed inside the electric power equipment, into a concentration level in the workplace atmosphere.

NOTE For example, a somewhat alarming by-product concentration of 1 000 ppmv, generated in a 1 l experimental chamber, will lead to the very low value of 0,04 ppmv when released into a 3 m × 3 m × 2,5 m room.

The second notion will determine the method of evaluating the potential health risk, applicable under either normal conditions (basic leakage) or abnormal ones (internal fault).

Under normal conditions the TLV (Threshold Limit Value) concentration should be employed, as reported in D.8.1. This ensures the safety of those working full time in the vicinity of the SF_6 filled electric power equipment.

Under abnormal conditions for example internal arc fault, personnel immediately leave the room of the electric power equipment and the exposure is hence momentary. For this type of exposure, very much higher concentrations than the TLV can be tolerated, as reported in D.4.2.

D.4 Calculation of by-product concentrations

The following presents the methods and results of calculations giving the concentrations of gaseous by-products in the equipment room atmosphere for various types of installation. The contributions of other sources of risk, which arise during an internal fault, such as smokes, fumes and vapours, have also been assessed.

For the case of leakage, the quantities of SOF_2 and S_2F_{10} leaked during 24 h are considered. It is assumed that no gas escapes from the equipment room. The effects of hydrolysis of SOF_2 are considered.

For the internal fault situations all of the SOF_2 formed is considered to be emitted rapidly into the surrounding atmosphere and is considered to be stable during the time period of interest.

For the case of maintenance of electric power equipment, particular to controlled and/or closed pressure systems, guidance is given in Clause 9. In such situations working procedures require the recovery of all the SF_6 before opening the electric power equipment.

D.4.1 Calculation criteria

The following criteria have been used throughout this treatment, for both leakage and internal fault situations:

- The equipment room is assumed to be completely closed and ventilation is assumed to be inoperative during the period of interest.
- Arc by-product adsorbers, fitted in the electric power equipment, are assumed to be inoperative during the period of interest.
- The gas emitted is assumed to mix uniformly with the air in the room of the electric power equipment in a short time with respect to the working day or exposure duration.

D.4.2 Risk evaluation

D.4.2.1 Leakage situations

The results of the example calculations give the concentrations C of SOF_2 (see D.4.5) and of S_2F_{10} (see D.4.6) in the air of the room of the electric power equipment. Each value of C should be compared with the concentration permitted for full-time work, the TLV reported in D.8.1. The final result of each calculation is expressed as a ratio C/TLV; this should have a value of less than unity for there to be no significant risk and for full-time working to be permitted.

The concentrations of SO_2 and HF are calculated for the case of SOF_2 hydrolysis (see D.4.5.1). HF and SO_2 are considered to have a cumulative effect on the human organism and for such a multi-component mixture, the sum R_{tot} of the individual ratios of concentration to TLV should not exceed unity.

$$R_{\text{tot}} = \frac{\text{SO}_2 \text{ concentration}}{\text{TLV}(\text{SO}_2)} + \frac{\text{HF concentration}}{\text{TLV (HF)}} \leq 1$$

NOTE This is a cautious assumption which results in the maximum permitted concentration of each component being lower than its TLV. It is adopted here in order to maintain a worst-case approach.

The TLVs for the four compounds of interest, SOF_2, SO_2, HF and S_2F_{10}, are given in Table D.1 [10]:

Table D.1 – TLVs for SOF_2, SO_2, HF, and S_2F_{10}

	SOF_2	SO_2	HF	S_2F_{10}
TLV (ppmv)	1,6	2	3	0,01

D.4.2.2 Internal fault situations

For these abnormal cases the SOF_2 concentrations are much higher than for leakage because all of the SF_6 is released in a short period of time. Standard procedures impose evacuation and ventilation of the equipment room. The exposure to arc decomposed SF_6 should therefore be momentary. For this reason, comparing a calculated SOF_2 concentration with the TLV is no longer appropriate (see D.8.1).

In general, an IDLH (Immediately Dangerous to Life or Health) value provides guidance for short-term exposure (see D.8.2). There is however no published IDLH value for SOF_2. It is therefore necessary to turn to the results of toxicological data in order to obtain a reference value for non-repetitive momentary exposure (C_m).

$$C_m = 500 \text{ ppmv}$$

NOTE Toxicological data exist for exposure of test animals to atmospheres containing SOF_2 [26] and [27], covering the effects of 1 h exposure of three distinct mammal species to concentrations of up to several thousand ppmv of SOF_2. The results show that for exposure to concentrations of up to 100 ppmv (mice and rats) and 500 ppmv (rabbits), all animals exhibit an apparently normal general state, 24 h after the exposure period.

The calculated SOF_2 concentrations are compared with C_m to assess the risks to health due to by-products during or following an internal fault. Other factors which may be more significant should be considered in risk assessment and in the appraisal of safety procedures (see D.4.7.2 and D.4.7.3).

For human exposure, higher concentrations than 500 ppmv for 1 h could be tolerable, as larger organisms are generally less sensitive to toxic agents. It can therefore be inferred that the use of a momentary exposure limit, C_m of 500 ppmv, as a reference value for comparison with the calculated concentrations, is acceptable.

D.4.3 Calculation limits for cases of internal fault

D.4.3.1 Very small room volumes

In these situations, such as for an internal fault in a medium-voltage/low-voltage substation, the main health risk is not that due to arc by-products. The arc itself, the hot gas blast, the smoke, the fumes from burnt paint, plastics or metal vapours and finally the shock wave, probably constitute the major risks, as reported in D.4.7.2 and D.4.7.3.

Extrapolation to room volumes much smaller than about 50 m^3 is hence probably not a valid procedure for estimating health risks. An example calculation using a smaller room volume than 50 m^3 has nevertheless been included to allow the SOF_2 contribution to the overall toxicity to be estimated.

D.4.3.2 Very long arcing times

For all internal fault calculations a constant environment for the arc is assumed, leading to a constant SOF_2 production rate, during an arcing time of 100 ms (see D.7.3.2). The constant production rate will almost certainly not be valid for arcing times above about 100 ms, as explained below:

Internal fault in MV and HV circuit-breakers and in ring main units (RMU)

In these cases, the vent valve will rapidly open the gas-filled compartment to the atmosphere. The high, arc-induced, pressure rise will tend to empty most of the SF_6 in a fraction of a second but the arc will remain burning mainly in the metal vapour formed by evaporation of the electrodes. Clearly, only a fraction of the total arc energy goes to by-product formation. Experimental work is thus needed to enable extrapolation above about 100 ms.

Internal fault in gas insulated switchgear (high-voltage GIS)

In these situations, a significant quantity of metallic vapour is formed and an exothermic reaction takes place between the SF_6 and the aluminium electrodes. The arcing environment will be profoundly modified and the use of a constant by-product production rate may not be justifiable.

D.4.4 Situations studied

Ten representative situations have been studied as follows:

a) Leakage from a medium-voltage circuit-breaker after three consecutive interruptions of a 31,5 kA three-phase fault current (see IEC 62271-100, test duty T100).

b) Leakage from a high-voltage circuit-breaker after three consecutive interruptions of a 31,5 kA three-phase fault current (see IEC 62271-100, test duty T100).

c) Leakage from a high-voltage gas-filled compartment in which partial discharges have occurred during a period of 30 years.

d) Leakage from a high-voltage gas-filled compartment in which corona discharges have occurred during a period of 30 years.

e) Leakage from a high-voltage switch-disconnector in which sparking has occurred 200 times per year during a period of 30 years.

f) Internal fault leading to pressure-relief or burn-through in a 245 kV GIS bus-bar at 40 kA (single-phase fault).

g) Internal fault leading to pressure-relief or burn-through in a 145 kV GIS bus-bar at 31,5 kA (fault involving two phase-to-phase arcs).

h) Internal fault leading to pressure-relief or burn-through in a medium-voltage GIS switchboard at 25 kA (single-phase fault).

i) Internal fault leading to pressure-relief in a medium-voltage circuit-breaker at 25 kA (single-phase fault).

j) Internal fault leading to pressure-relief in a medium-voltage ring main unit at 16 kA (fault involving two phase-to-phase arcs).

D.4.5 Determination of concentrations due to leakage of SOF_2 from circuit-breakers

Leakage from circuit-breakers only is considered here because the degree of SF_6 decomposition in circuit-breakers is higher than that in other types of equipment.

The concentration of the reference gaseous by-product SOF_2 in the room of the electric power equipment is calculated for a circuit-breaker which has just interrupted a three-phase fault current three consecutive times (as required by IEC 62271-100, T100) and is consequently leaking SF_6 containing by-products. The quantity of SOF_2 leaked during a 24 h period is calculated and compared with the room volume to establish the concentration.

The procedure for calculating the concentrations of by-products is as follows. Data and intermediate calculation results are given in D.7 as indicated for each stage.

- Calculate the total arc energy in kilojoules (kJ) ($E = I \times U \times t \times n \times m$) where n is the number of phases and m is the number of interruptions (see D.7.3.1 for data).
- Calculate the quantity of SOF_2 formed in litres (from production rate, r, in l/kJ, see D.7.4 and D.7.5.

NOTE 1 The arcing takes place between copper-tungsten contacts.

- Calculate the SOF_2/SF_6 volume ratio inside the breaker (taking into account the filling pressure, see D.7.7).
- Determine the leakage rate L in litres per day (from manufacturer's data, see D.7.6).
- Calculate the quantity of SOF_2 leaking into the equipment room (see D.7.7).
- Calculate the quantity of SOF_2 accumulated during a 24 h period (in litres, see D.7.7).
- Calculate the ratio of accumulated SOF_2 to the volume of air in the equipment room (in ppmv, see D.7.1 for data).
- Compare this concentration with the TLV (see D.8.1) and express the result as a ratio $R = C/\text{TLV}$. If $R < 1$, then no health risk is expected.

The equation for calculation of the concentration of SOF_2 in the equipment room C, in ppmv, for a 24 h period is thus:

$$C = \frac{r \times E \times L \times 10^6}{V \times v \times \cdot p_\mathrm{f}}$$

where

r is the production rate in l/kJ;

E is the arc energy, in kJ;

L is the leakage rate, in l/day;

V is the room volume, in l;

v is the volume of the compartment of the electric power equipment, in l;

p_f is the ratio of the SF_6 filling pressure (MPa absolute) referred to the atmospheric pressure.

The results of the example calculations for leakage situations (see D.7 for data) is given in Table D.2.

Table D.2 – Results of example calculations for leakage situations

Circuit-breaker	V_l **SOF_2 leaked** l	V **Room volume** l	C **SOF_2 concentration** ppmv	**TLV (NOTE) of SOF_2** ppmv	R
MV	$1,3 \times 10^{-6}$	120×10^3	11×10^{-6}	1,6	$6,8 \times 10^{-6}$
HV	108×10^{-6}	700×10^3	154×10^{-6}	1,6	96×10^{-6}
NOTE TLV: Threshold Limit Value: exposure levels based on repetitive 8 h exposure [28] (see D.8.1).					

V_l is the quantity leaked into the atmosphere in 24 h (see D.7.5, D.7.6 and D.7.7). The concentrations C are very much smaller than the TLV, as shown by the values of ratio R.

NOTE Extrapolation to longer accumulation times requires detailed data concerning the rate of air replacement due to ventilation.

D.4.5.1 Additional calculation to take account of the effects of SOF_2 hydrolysis

In C.1.1, equation (9) describes the hydrolysis of SOF_2 whereby SO_2 and HF are formed. This can occur when SOF_2 remains in the presence of moisture for long periods of time, either inside the gas-filled compartment of the electric power equipment or in the atmosphere contained in the equipment room. Adsorbers maintain a low moisture level inside the gas-filled compartment, limiting the degree to which hydrolysis can occur prior to leakage. Normal ventilation prevents the accumulation of SOF_2 in the atmosphere.

Assuming that inadequate ventilation does allow SOF_2 to accumulate, it is necessary to consider the final products in evaluating any risk to health.

Each molecule of SOF_2 involved in the hydrolysis reaction gives rise to one molecule of SO_2 and two molecules of HF. Thus, every mole of SOF_2 gives rise to one mole of SO_2 and two moles of HF, each mole occupying the molar volume. Therefore, a given volume of SOF_2 produces an equal volume of SO_2 and twice that volume of HF and the concentrations in a given room volume are similarly related. HF, however, is highly reactive and is unlikely to remain in the atmosphere for long enough for high concentrations to be reached.

HF and SO_2 are considered to have a similar effect on the human organism and for such a multi-component mixture; the sum R_tot of the individual ratios of concentration to TLV should not exceed unity.

$$R_{\text{tot}} = \frac{\text{SO}_2 \text{ concentration}}{\text{TLV (SO}_2\text{)}} + \frac{\text{HF concentration}}{\text{TLV (HF)}} \leq 1$$

NOTE This is a cautious assumption which results in the maximum permitted concentration of each component being lower than its TLV. It is adopted here in order to maintain a worst-case approach.

Assuming that all the SOF_2 undergoes hydrolysis and that all of the resultant SO_2 and HF remain in the atmosphere, the results of D.4.5 give the following values of R_{tot}. The very low values of R_{tot} (and of the individual ratios of concentration referred to the TLVs) indicate negligible risk.

Table D.3 – Results for leakage situations taking account of SOF_2 hydrolysis

Circuit-breaker	SOF_2	SO_2		HF		R_{tot}
	Concentration ppmv	**TLV** ppmv (NOTE)	**Concentration** ppmv	**TLV** ppmv (NOTE)	**Concentration** ppmv	
MV	11×10^{-6}	2,0	11×10^{-6}	3,0	22×10^{-6}	$12{,}6 \times 10^{-6}$
HV	154×10^{-6}	2,0	154×10^{-6}	3,0	308×10^{-6}	180×10^{-6}
NOTE The TLVs for SO_2 and HF are given in references [27] and [28].						

D.4.6 Determination of concentrations due to leakage of S_2F_{10}

The rates of decomposition of SF_6 in the presence of low-energy discharges are generally considered to be extremely low for normal service conditions, implying a negligible risk to health. For partial discharge (PD) and corona activity this is mainly due to the fact that the energies involved are extremely low; significant decomposition would only occur if the discharges were active during a prolonged period of time (weeks or months). Moreover:

- Partial discharge activity located inside solid insulators cannot affect the gas;
- SF_6 filled electric power equipment is generally corona free and any significant corona discharges detected usually originate outside the equipment, for example on bushings, etc;
- Standard PD testing procedures shields equipment for this type of discharge, as do radio interference measurements.

Arcing of high-voltage disconnectors has limited impact firstly because the overall energy per operation is low, secondly because the time between operations is very long in typical service conditions and thirdly because the peak arcing current is high.

However, regardless of the above, concern has been voiced as to the possible existence of S_2F_{10} in electric power equipments because of its high relative toxicity [22], even though it is known to decay rapidly in practical situations [23].

In order to illustrate the extremely low health risk associated with S_2F_{10} in practical situations, estimations are presented below for the three cases cited above. Severe scenarios have been adopted for each situation.

The precise values of discharge energy employed can be multiplied by many orders of magnitude without significantly modifying the conclusions. This provides a considerable margin of safety to allow for abnormally high discharge levels.

The approach to the calculations is similar for each case:

- It is assumed that the discharge activity forms unconditionally stable S_2F_{10} which accumulates for 30 years inside the electric power equipment;

- This gas then leaks into the room containing the electric power equipment (700 m^3) at the standard rate of 1 % per year (27×10^{-6} per day);
- The quantity built up in 24 h is then estimated and the concentration C found is compared to the TLV, (0,01 ppmv) [28], to give the ratio R;
- Ratios R much less than unity clearly imply that the risk to health would be negligible.

NOTE The decay rates reported in the references cited lead to S_2F_{10} concentrations about 100 times smaller than those estimated here.

In the three cases studied, the calculated maximum concentrations built up are in the region of 5 orders of magnitude less than the TLV. This result implies that in practice there is no risk to health due to S_2F_{10} produced in electric power equipments under low-energy discharge conditions of this nature. The decay of S_2F_{10} in practical situations should greatly reduce the quantity accumulated, considerably reinforcing this conclusion. Furthermore, the calculations neglect any reduction in S_2F_{10} production rates due to the presence of moisture.

D.4.6.1 Partial discharge situation

The following assumptions are made:

- The PD level in the gas is 5 pC;

NOTE 1 This is a typical maximum level used during acceptance testing of GIS.

- The number of discharges per cycle is high;

NOTE 2 All discharges have identical amplitudes and are assumed to be distributed uniformly over the voltage wave.

- The nominal voltage is 245 kV at a frequency of 50 Hz;
- The S_2F_{10} production rate is $0,2 \times 10^{-9}$ mol/J;

NOTE 3 S_2F_{10} production rates for partial discharges under a.c. excitation are not available in the literature. This calculation is therefore based on an extrapolation of the results of spark discharge measurements.

- The discharges run continuously for 30 years and the S_2F_{10} formed does not decay.

The results are shown in the following Table D.4. The quantity of S_2F_{10} leaked during the 24 h period would be extremely small ($88,3 \times 10^{-9}$ l), the concentration built up would be $C = 126 \times 10^{-9}$ ppmv and the ratio $R = C/\text{TLV}$ would be $12,6 \times 10^{-6}$.

Table D.4 – Sample calculation of S_2F_{10} concentration for partial discharges

Charge transferred per discharge	Q	5 to 10^{-12} C
Number of discharges per cycle	N	20
Charge transferred per cycle	$Q = q \times n$	$0,1 \times 10^{-9}$ C
Rated voltage	U_r	245 kV
Energy dissipated per cycle	$E = Q \times U_r / \sqrt{3}$	$14,1 \times 10^{-6}$ J
Energy dissipated per second	$E_s = 50 \times E$	$0,707 \times 10^{-3}$ J
Energy dissipated per year	$E_y = 31,5 \times 10^6 \times E_s$	$22,3 \times 10^3$ J
S_2F_{10} production rate	R	$0,2 \times 10^{-9}$ mole/J
S_2F_{10} produced per year	$P = r \times E_y$	4,46 x 10^{-6} mole
Volume S_2F_{10} in litres (per year)	$V = 24,45 \times P$	109 x 10^{-6} l
S_2F_{10} accumulated in 30 years	$U = 30 \times V$	$3,27 \times 10^{-3}$ l
S_2F_{10} leaked in 24 h	$v = 27 \times 10^{-6} \times U$	$88,3 \times 10^{-9}$ l
Concentration (700 m^3 room)	$C = v/(700 \times 10^3)$	126×10^{-9} ppmv
TLV for S_2F_{10}	TLV	0,01 ppmv

Ratio R	$R = C$/TLV	12,6 x 10^{-6}

D.4.6.2 Corona situations

For discharge activity inside the electric power equipment, the following assumptions are made:

- The overall corona voltage (RIV) is 3 µV measured across 300 Ω;
- The rated voltage is 245 kV;
- The S_2F_{10} production rate is $0,05 \times 10^{-9}$ mole/J. S_2F_{10} does not decay.

As shown by the following table, the S_2F_{10} leaked during the 24 h period would be about 45×10^{-9} l, the concentration C would be 64×10^{-9} ppmv and the ratio $R = C$/TLV would be $6,4 \times 10^{-6}$.

Table D.5 – Sample calculation of S_2F_{10} concentration for corona discharges

Corona voltage	V_c	3×10^{-6} V
Measurement impedance	Z	300 Ω
Corona current	$I = V_c/Z$	$0,1 \times 10^{-9}$ C
GIS rated voltage	U_r	245×10^{3} V
Energy dissipated during one second	$E_s = I \times U_r/\sqrt{3}$	$14,1 \times 10^{-3}$ J
Energy dissipated per year	$E_y = 31,5 \times 10^{6}\, E_s$	$44,5 \times 10^{3}$ J
S_2F_{10} production rate	R	$0,05 \times 10^{-9}$ mole/J
S_2F_{10} produced per year	$P_v = r \times E_y$	$2,2 \times 10^{-6}$ mole
S_2F_{10} volume per year	$V = 24,45 \times P_y$	$54,4 \times 10^{-6}$ l
S_2F_{10} accumulated in 30 years	$U = 30\, V$	$1,63 \times 10^{-3}$ l
S_2F_{10} leaked in 24 h	$v = 27 \times 10^{-6} \times U$	$44,7 \times 10^{-9}$ l
Concentration (700 m^3 room)	$C = V\, /\, (700 \times 10^{3})$	$63,8 \times 10^{-9}$ ppmv
TLV for S_2F_{10}	TLV	0,01 ppmv
Ratio R	$R = C$/TLV	$6,4 \times 10^{-6}$

D.4.6.3 Disconnector sparking

The following assumptions are made:

- The disconnector operates 200 times per year. The energy per operation is 0,25 kJ;

NOTE 1 The average values used are: arc voltage, 1 kV and capacitive current, 0,25 A. The arc duration is 1 s.

- The production rate is $0,05 \times 10^{-9}$ mole/J and the S_2F_{10} formed does not decay.

NOTE 2 The individual arcs during disconnector sparking can have peak currents of up to 3 kA but last only a few tens of microseconds. In the absence of published data, the production rate chosen reflects this situation being at the lower end of the spark discharge range but more than 2 000 times greater than for high power arcs.

As shown by the following table, the S_2F_{10} leaked during the 24 h period would be 50×10^{-9} l, the concentration built up would be $C = 72 \times 10^{-9}$ ppmv and the ratio $R = C$/TLV would be 7,2 x 10^{-6}. These theoretical estimates have been confirmed as being realistic by measurements on a real disconnector under highly accelerated operation conditions [23].

Table D.6 – Sample calculation of S_2F_{10} concentration for disconnector sparking

Energy per operation	$E_o = I \times u \times t$	0,25 kJ
Energy dissipated per year	$E_y = 200\ E_o$	50 kJ
Production rate S_2F_{10}	R	$0{,}05 \times 10^{-9}$ mole/J
S_2F_{10} produced per year	$P_y = r \times E_y$	$2{,}5 \times 10^{-6}$ mole
S_2F_{10} volume per year	$V = 24{,}45 \times P$	61×10^{-6} l
S_2F_{10} accumulated in 30 years	$U = 30 \times V$	$1{,}8 \times 10^{-3}$ l
S_2F_{10} leaked in 24 h (litres)	$V = 27{,}4 \times 10^{-6} \times U$	50×10^{-9} l
Concentration (700 m^3 room)	$C = V / (700 \times 10^3)$	72×10^{-9} ppmv
TLV for S_2F_{10}	TLV	0,01 ppmv
Ratio R	$R = C/\text{TLV}$	$7{,}2 \times 10^{-6}$

D.4.7 Determination of concentration due to internal fault

An internal fault does not necessarily cause SF_6 to be released. The only situations in which a release will occur are:

- Failures provoking over-pressure relief operation or gas-filled compartment opening;
- Internal fault situations provoking arc burn-through of the gas-filled compartment.

The assumptions made for these situations, in addition to those given in D.4.1, are as follows:

- The totality of gaseous by-products formed is rapidly exhausted into the surrounding air;
- The very strong convective and gas blast forces induce rapid mixing of the emitted gas with the air in the equipment room;
- The SOF_2 generated is assumed to be stable during the time period of interest.

The SOF_2 concentration in the equipment room air is calculated as follows for each situation. Data and intermediate results are given in D.7 as indicated for each step:

- Calculate the arc energy E, in kJ (see D.7.3.2);
- Calculate the quantity V_f of SOF_2 formed in l (from production rates, r, in l/kJ, see D.7.4 and D.7.5);
- Calculate the volume of the equipment room V, in l (see D.7.1).
- Calculate the ratio C of SOF_2 volume/equipment room volume, in ppmv.
- Compare this SOF_2 concentration to the momentary exposure limit C_m for SOF_2. The basic equation for room concentration C of SOF_2 in volume ppmv is thus:

$$C = \frac{r \times E \times 10^6}{V}$$

Results of example calculations for internal fault situations (see D.7 for data) are given in Table D.7.

Table D.7 – Sample calculation of SOF_2 concentrations for internal fault situations

Internal fault	V_f SOF_2 formed l	V Room volume l	C SOF_2 concentration ppmv	C_m (NOTE 1) for SOF_2 ppmv
245 kV GIS	60	$2\,000 \times 10^3$	30	500
145 kV GIS	95	700×10^3	135	500
MV GIS	11,3	120×10^3	94	500
MV CB	1.9	120×10^3	15	500
MV RMU (Note 2)	3,0	30×10^3	100	500

NOTE 1 For C_m, see D.4.2.2.

NOTE 2 In this case the room volume is small, see D.4.3.1.

D.4.7.1 Estimate of the relative contributions of by-product

Arc decomposed SF_6 is a multi-component product. The relative contribution of each component to the risk of exposure should be evaluated by dividing the concentration C of that component by the corresponding permissible level (TLV, IDLH, etc.). The smaller the ratio found, the lower the contribution to overall toxicity. Comparing the ratios obtained for the different components indicates their relative importance. This is illustrated by considering the results obtained for the well-known by-products SOF_2, SO_2F_2 and S_2F_{10} for which reliable data are available [22], [26], and [28].

NOTE 1 The production rates used are SOF_2: 3,7 ml/kJ; SO_2F_2: 0,06 ml/kJ; S_2F_{10}: $2,4 \times 10^{-6}$ ml/kJ. The TLVs are SOF_2: 1,6 ppmv; SO_2F_2: 5 ppmv and S_2F_{10}: 0,01 ppmv. For short-term exposure, C_m for SOF_2 is 500 ppmv; the IDLH values are SO_2F_2: 1 000 ppmv and S_2F_{10}: 1,0 ppmv [26].

NOTE 2 The experimental conditions used in obtaining the production rate data differ between researchers. The orders of magnitudes are nevertheless thought to be comparable for the purpose of these estimations.

Applying the method of D.4.7 to the medium-voltage circuit-breaker example yields the following C/TLV ratios:

$$SOF_2 = 9,3 \qquad SO_2F_2 = 0,05 \qquad S_2F_{10} = 0,001$$

For short-term exposures, the ratios shown below are calculated as C/C_m for SOF_2 and as C/IDLH for the other by-products:

$$SOF_2 = 3,0 \times 10^{-2} \qquad SO_2F_2 = 2,5 \times 10^{-4} \qquad S_2F_{10} = 4,0 \times 10^{-5}$$

Both cases clearly show the negligible contribution of S_2F_{10} and above all, the dominance of SOF_2.

Even a variation of two orders of magnitude in the S_2F_{10} production rate has no influence on this conclusion. Although S_2F_{10} may exist in arc decomposed SF_6, its high toxicity is greatly offset by the extremely small quantities formed. Its presence may thus be neglected in so far as overall toxicity is concerned.

D.4.7.2 Contribution of metallic vapours

During high power fault arcing in any medium, the energy dissipated at the electrodes by the arc roots melts and evaporates large quantities of metal. In the event of an internal fault leading to the opening of the gas-filled compartment, most of the fumes formed will be expelled into the equipment room and will constitute a contribution to the overall toxicity.

As a first approximation, the upper limit of this contribution can be estimated by assuming all the energy injected from the arc roots to go to heating, melting, and then evaporating the metal which is then exhausted into the room. The results can then be compared with experimental arc erosion data to check the orders of magnitude.

This treatment is however not valid for high-voltage burn-through situations due to the strong exothermic reactions which occur between aluminium vapour and SF_6 and which further increase vapour production. Overlooking this would give rise to a gross under-estimation of the amount of metal vapour produced for a given arc energy.

The following comments apply to the results of these calculations:

- For internal faults the contribution of arc decomposed SF_6 should not automatically be assumed to dominate the overall toxicity of the atmosphere. Regardless of the approximate nature of this calculation, it indicates that, for both medium-voltage situations of D.4.4, copper fumes may dominate the overall toxicity.
- This conclusion can be seen to remain valid even if only 10 % of the energy dissipated at the arc roots goes to vapour formation, or if 90 % of the vapour formed is condensed or transformed inside the electric power equipment.
- Similar safety precautions should therefore be applied to all electric power equipment, regardless of the insulation medium. It may well be advisable to build these safety precautions around a solid understanding of metal vapour generation rather than on SF_6 decomposition values.

This treatment ignores the presence of chemical reactions between the metal vapour and the insulating gas.

In the absence of more reliable methods, the following approximate treatment has the merit of highlighting a potential major contributor to overall toxicity in an internal arc situation involving any type of switchgear or controlgear.

The procedure followed for estimating the absolute maximum contribution of copper fumes to toxicity is as follows; it assumes all the energy dissipated by the arc roots to go to metal vapour formation:

- The total anode plus cathode voltage drop is taken as about 30 V. This gives an energy injected into the electrodes of 75 kJ and 96 kJ respectively for the medium-voltage circuit-breaker and RMU of D.4.4, cases i) and j).
- The energy required to transform one mole of copper, initially at room temperature, into vapour has been calculated to be 390 kJ.
- Comparing the above values gives upper limits for the quantities of vapour formed in each case as 0,19 moles for the medium-voltage circuit-breaker and 0,25 moles for the RMU.
- Based on a molecular weight of 64 g/mole for copper, these values correspond to 12 g and 15,8 g of evaporated metal respectively.
- This represents erosions of about 1,4 cm^3 and 1,8 cm^3 of metal which is reasonable given the arc energies involved.
- These values are about 40 % higher than those extrapolated from experimental data obtained for multiple-shot, 4 kA tests, which give erosion rates between 2,5 mg/A/s and 4,5 mg/A/s copper electrodes.
- Employing the equipment room volumes given in D.7.1 of 120 m^3 and 30 m^3 respectively, final concentrations of about 100 mg/m^3 and 520 mg/m^3 are obtained.
- This is compared to the TLV of copper of 0,2 mg/m^3 [28].

NOTE These results, using approximate data and methods, have been derived theoretically and have not been substantiated practically.

D.4.7.3 Contribution due to the combustion of plastics

This subject has not been treated as such, being outside the general scope of this report. However, the highly significant potential toxic contribution of these elements justifies their consideration. The combustion of plastic materials, such as wire insulation, following an internal fault, will produce a variety of toxic fumes, independent of the technology which the electric power equipment is based on.

As an example, the case of polyvinyl chloride (PVC) will be considered. The TLV for vinyl chloride is 1 ppmv = 2,6 mg/m^3 [28]. This means that the full vaporisation of only 8 g will raise the atmospheric concentration of a 30 m^3 room to 100 times the TLV. For a 120 m^3 room, 32 g of PVC will give the same result. This represents the insulation of 1,2 m of standard 1 mm diameter wire.

A normal medium-voltage equipment room can contain several km of wire of these dimensions, comprising about 7 kg of PVC per km.

These estimations can be carried out for each of the plastic materials susceptible to combustion during an internal fault. The preceding observations indicate that the contribution of fumes due to the combustion of plastics should not be ignored and that exposure to such fumes should be kept as low as is reasonably practicable.

The conclusion is that the presence of SF_6 in electric power equipment adds little to the toxicity of the atmosphere generated by an internal fault. This was indeed the conclusion drawn by a study carried out in 1987 [6].

Procedures and regulations should not thus single out electric power equipment using SF_6 as requiring separate treatment.

NOTE PVC vapours react with other products in the atmosphere to produce less toxic by-products. The above is hence a worst-case situation.

D.5 Assessment of results

D.5.1 Leakage situations

The by-products, formed by arcing and by low-energy discharges, released due to leakage from SF_6-filled electric power equipments, reach negligible concentrations in the workplace atmosphere. Under worst-case conditions the concentrations found for both medium-voltage and high-voltage cases are 4 orders of magnitude lower than the TLVs.

There is no cause for concern and no need for precautions other than the normal ventilation practices for low-lying areas. This conclusion is reinforced in consideration of the initial simplifying assumptions made in D.4.1.

Even in the case of abnormal leakage situations (a leakage rate for example 3 orders of magnitude higher than the normal rate), these conclusions are unchanged.

D.5.2 Internal fault

To illustrate these cases, five rare but plausible situations covering the medium- and high-voltage spectrum have been chosen. In the most severe of these situations, the equipment room concentrations of SOF_2 remain below the momentary exposure limit C_m (see D.4.2).

In any situation of this sort, basic safety procedures include evacuation rules designed to ensure that personnel are not exposed to exhausted materials for more than a few minutes. Furthermore, forced ventilation and/or venting ensure the reduction of the concentration levels to much lower values within minutes. The added safety margins inherent in the application of either or both of the above are considerable.

Therefore simple safety procedures will ensure that the practical exposure will be momentary and that the health of personnel will not be jeopardised.

D.5.3 Outdoor installations

Both for leakage and failure cases the calculations are carried out in an identical manner as above, but in this case the volume of air into which the arc decomposed SF_6 escapes is large if not infinite. Prevailing winds and the high exhaust velocity also speed up dispersion. Clearly, for the cases of leakage, the concentrations obtained will be infinitesimal. For the internal fault cases, within seconds the concentrations will fall well below the TLV values.

In conclusion no health risk is to be expected due to the toxicity of by-product emission from outdoor electric power equipment.

D.6 Conclusions

The results of the sample calculations, based on the state-of-the-art, show that, for leakage situations, there is no risk to health due to exposure to by-products.

The results also show that, in the unlikely event of an internal fault leading to a release of SF_6, significant concentrations of by-products can occur in an equipment room. However, the calculated concentrations do not exceed a substantiated limit for short-term exposure.

It is thus concluded that, as long as safety procedures are followed, there is minimal risk specifically associated with the use of SF_6 in electric power equipment.

It has also been stressed that in any internal fault situation, corrosive and/or toxic fumes are produced whether or not SF_6 is present. In cases where these fumes enter the ambient atmosphere of the switchgear room, it has been shown that non-SF_6 related arc products are likely to be the dominant contributors to overall toxicity. This further strengthens the view that the use of SF_6 in electric power equipment does not significantly add to the risks associated with an internal fault.

D.7 Data for calculations

D.7.1 Typical volumes for the equipment rooms

245 kV GIS hall (7 bays): 25 m × 12 m × 6,5 m = 2 000 m^3

145 kV GIS hall (7 bays): 12,5 m × 8 m × 7 m = 700 m^3

MV distribution hall (used for CB and MV GIS cases) (15 circuit-breaker panels): 10 m × 4 m × 3 m = 120 m^3

MV RMU room (1 ring main unit) (see also D.4.3.1): 4 m × 3 m × 2,5 m = 30 m^3

D.7.2 Switchgear and controlgear volume and filling pressure

Table D.8 – Switchgear volume and filling pressure

	Volume l	**Pressure** MPa absolute
Medium-voltage circuit-breaker	45	0,3

	Volume l	Pressure MPa absolute
Medium-voltage RMU	200	0,1
Medium-voltage GIS	1 000	0,1
High-voltage circuit-breaker	500	0,5
GIS bus-bar	2 000	0,3

D.7.3 Arcing characteristics

D.7.3.1 Fault current interruption/leakage situation

Arc energy figures are totals for three interruptions of three-phase fault current, i.e. nine times the value for one single-phase interruption.

Table D.9 – Arc energies for interruptions

	I kA	U_{arc} V	T_{arc} ms	$9 \times E_{arc}$ kJ
Medium-voltage circuit-breaker	31,5	200	15	851
High-voltage circuit-breaker	31,5	500	15	2 126

D.7.3.2 Internal fault/exhaust situation

Arc energy figures are for N simultaneous arcs. The number of arcs has been chosen to represent the most likely internal fault situation.

Table D.10 – Arc energies for internal faults

	I kA	U_{arc} V	T_{arc} ms	N	E_{arc} kJ
245 kV GIS	40	1 000	100	1	4 000
145 kV GIS	31,5	1 000	100	2	6 300
Medium-voltage GIS	25	300	100	1	750
Medium-voltage circuit-breaker	25	200	100	1	500
Medium-voltage RMU	16	250	100	2	800

The values for arc time represent a compromise between real arcing times, rupture-disk operation, and burn-through, constancy of the arcing environment and validity domain of available production rate data. Linear extrapolation above about twice these values is thus expected to grossly overestimate the results (see D.4.3.2).

D.7.4 SOF_2 production rates

The quantity of gas formed during an electrical discharge is quoted generally as a quantity generated per joule of energy dissipated (the production rate, r).

Experimentally determined SOF_2 production rates depend on the electrode material used and the type of discharge considered. Exothermic reactions, which occur with aluminium electrodes, seem to enhance the production rate.

Experimental results are generally quoted in mol/J but in most practical cases it is more convenient to convert this to l/kJ. This conversion is effected using the fact that one mole of any gas occupies 24,45 l, at 25 °C and at atmospheric pressure.

The values used here have been averaged over the range of presently available data found in the literature [21] and [25].

Table D.11 – SOF_2 production rates

Electrode material	SOF_2 production rate(*r*)	
	mol/J	l/kJ
Cu, Fe, WCu	150×10^{-9}	$3{,}7 \times 10^{-3}$
Al	150×10^{-9}	15×10^{-3}
NOTE Aluminium electrodes are assumed only for GIS bus-bar situations.		

D.7.5 Quantity of SOF_2 formed

This is found from arc energy and production rates.

Table D.12 – Quantities of SOF_2 formed

	Medium-voltage		High-voltage	
	mol	l at 0,1 MPa	mol	l at 0,1 MPa
Leakage	0,13	3,15	0,319	7,87
Internal fault				
245 kV GIS			2,4	60
145 kV GIS			3,8	95
MV GIS	0,45	11,25		
MV CB	0,075	1,9		
MV RMU	0,12	3,0		

D.7.6 Leakage rates

Leakage rates for sealed-for-life electric power equipments are given as SF_6 volume lost per second per bar gauge of filling pressure.

For refillable electric power equipments the leakage rate is given as a percentage of total gas loss per year.

Typical values for three-phase circuit-breakers are given below with conversion into total leaked SF_6 per day (24 h) and, for the medium-voltage case, per bar MPa of filling pressure.

Table D.13 – SF_6 leakage rates

	MV breaker	HV breaker
Basic rate	3×10^{-6} cm^3/s/MPa gauge	0,5 % total SF_6 volume l/year
Daily rate	27×10^{-5} l/day/MPa gauge	$13{,}7 \times 10^{-6} \times (SF_6$ vol) l/day

D.7.7 SOF_2 leakage rates (using data from D.7.5 and D.7.6)

Table D.14 – SOF_2 leakage rates

	MV breaker	**HV breaker**
Volume SOF_2 formed (litres at 0,1 MPa absolute)	3,15	7,87
Total volume of SF_6 (litres at 0,1 MPa absolute)	135	2 500
SOF_2/SF_6 ratio inside circuit-breaker	2,33 % by vol.	0,31 % by vol.
Filling pressure (MPa absolute)	0,3	0,5
Leakage SOF_6 (litres per day) (see NOTE)	$1,26 \times 10^{-6}$	$107,8 \times 10^{-6}$

NOTE This is the amount of SOF_2 accumulated after 24 h leakage in a non-ventilated room.

D.8 Exposure limits

Terms used to define tolerable exposure limits can be separated into two groups:

- those intended to specify conditions under which a person can work continuously with no protective equipment, for example, Threshold Limit Value (TLV);
- those used to specify exceptional or abnormal situations of momentary exposure under which a person should leave the room, for example, Immediately Dangerous to Life or Health (IDLH).

D.8.1 TLV – Threshold limit value

The Threshold Limit Value (TLV) is a term instigated by the American Conference of Industrial Hygenists (ACGIH). It refers to the maximum concentration of an element or substance, considered physiologically and physically acceptable during a specified exposure period.

The threshold limit value, time weighted average (TLV-TWA) is the time weighted average concentration at which a person can work for 8 h a day, 40 h a week with no adverse health effects. The averaging allows for instantaneous concentration levels of several times the TLV-TWA. Throughout this report the TLV-TWA is referred to simply as TLV and all references to TLV should be taken to mean TLV-TWA.

D.8.1.1 TLV for SOF_2

The official allowable workplace concentration of SOF_2 for full-time occupation (TLV) is expressed in terms of its fluoride content [27] and [28] as TLV = 2,5 mg of fluoride F/m^3 of air at 25 °C and atmospheric pressure.

This corresponds to 5,66 mg/m^3 of SOF_2 in air at 25 °C and atmospheric pressure.

Expressed as a volume-per-volume atmospheric concentration of SOF_2 as TLV = 1,6 ppmv.

NOTE 1 The TLV for SOF_2 has been quoted as 0,65 ppmv in certain publications. It appears that this value has been derived using the molecular weight of SOF_2 (86,1) rather than that of its fluoride content (2 x 19).

NOTE 2 The conversion is obtained by calculating the mass of SOF_2 (per 1 m^3 of air) which corresponds to the TLV, expressed as 2,5 mg of fluoride F/m^3 of air. The molecular weight ratio of SOF_2 to its fluoride content is 86,1 / (2 × 19) = 2,266; the mass of SOF_2 in 1 m^3 of air at the TLV is thus 2,5 × 2,266 = 5,66 mg SOF_2/m^3.

NOTE 3 The conversion from mg/m^3 to ppmv is carried out by multiplying by the molar volume (24,45 l at 25 °C) and dividing by the molecular weight (86,1 g/mol) [28].

D.8.2 IDLH – Immediately dangerous to life or health

This value of concentration is one from which a person can escape with no irreversible health effects, as long as the exposure does not exceed 30 min. [28].

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