

High-voltage switchgear and controlgear —

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

National foreword

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A list of organizations represented on this committee can be obtained on request to its secretary.

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**High-voltage switchgear and controlgear -
Part 303: Use and handling of sulphur hexafluoride (SF₆)
(IEC/TR 62271-303:2008)**

Appareillage à haute tension -
Partie 303: Utilisation et manipulation
de l'hexafluorure de soufre (SF₆)
(CEI/TR 62271-303:2008)

Hochspannungs-Schaltgeräte
und -Schaltanlagen -
Teil 303: Gebrauch von und Umgang
mit Schwefelhexafluorid (SF₆)
(IEC/TR 62271-303:2008)

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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.

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
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 treat- ment 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)

1) Undated reference.

2) Valid edition at time of issue.

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INTRODUCTION

SF₆ 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 SF₆-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 SF₆ sealed pressure systems is considered to be less than 0,1 % per year.

The long experience with the use of SF₆ 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 SF₆;
- 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 SF₆ losses and emissions during commissioning, service, operation and end-of-life treatment to a minimum.

Recently, the latest practical recommendations on the use of SF₆ 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.

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

HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

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

1 Scope

The scope of this technical report is to address the procedures for safe and environmental compatible handling of SF₆ during installation, commissioning, normal and abnormal operations, disposal at the end-of-life of high-voltage switchgear and controlgear. Storage and transportation of SF₆ are also covered.

These procedures should be regarded as minimum requirements to ensure the safety of personnel working with SF₆ and to minimize the SF₆ emission to the environment.

This technical report generally applies also to gas mixtures containing SF₆.

NOTE 1 For the use of this technical report, the term “high voltage” (reference IEC 601-01-27) is the rated voltage above 1 000 V. However, the term “medium voltage” (reference IEC 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 (SF₆) for use in electrical equipment*

IEC 60480, *Guidelines for the checking and treatment of sulphur hexafluoride (SF₆) 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 SF₆ as a dielectric and/or arc-quenching medium.

3.1

abnormal release of sulphur hexafluoride (SF₆)

release from equipment in service due to a failure in the pressure system

NOTE An abnormal SF₆ release is usually an un-wanted and continuous emission of gas. As soon as an abnormal SF₆ leakage is detected, appropriate measures to locate and eliminate the leak should be immediately arranged.

3.2

handling of sulphur hexafluoride (SF₆)

any process which might involve transfer of SF₆

3.3

evacuation

transfer of a gas different from SF₆ (for example air or N₂) from the gas compartment to the atmosphere. The operation is performed utilising a vacuum pump

3.4

recovery of sulphur hexafluoride (SF₆)

transfer of SF₆ 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 (SF₆)

filling with SF₆ a pre-filled compartment to the SF₆ rated filling pressure

NOTE Pre-filled compartments are closed pressure systems filled in the factory prior to shipment. They contain SF₆ 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 (SF₆)

a series of SF₆ handling including recovery and minimum SF₆ 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 SF₆ 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 SF₆ 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 (SF₆)

SF₆ gas having a very low level of impurities in accordance with IEC 60376

3.15

used sulphur hexafluoride (SF₆)

gas removed from an electrical equipment, initially filled with SF₆ 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 SF₆, which occur as gaseous and solid.

3.16

used sulphur hexafluoride (SF₆) suitable for reuse on site

used SF₆ 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 (SF₆) suitable for reuse at the gas manufacturer

used SF₆ 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 (SF₆) 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 (SF₆)

used sulphur hexafluoride (SF₆) 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 (SF₆)

used sulphur hexafluoride (SF₆) 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 (SF₆)

used sulphur hexafluoride (SF₆) 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 SF₆

Storage and transportation of SF₆, either in containers or in electric power equipment is always carried out in accordance with local and international regulations.

NOTE An empty SF₆ container may still contain a residual amount of SF₆. It should be stored and transported in the same way as for a filled container.

4.1 Storage of containers filled with SF₆

In general, SF₆ 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 SF₆.

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 SF₆ and used SF₆ suitable for reuse on site should be physically separated from those containing used SF₆ suitable for reuse at the gas manufacturer or used SF₆ 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 SF₆

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 SF₆ 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 SF₆

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 SF₆ 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 SF₆ 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 SF₆ 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 SF₆

International regulations for shipment of electric power equipment containing SF₆ and/or SF₆ 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 SF₆ are summarised in Table 3.

Table 3 – International regulations for shipment of SF₆

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 SF ₆ 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 SF₆ NOTE 2 Any used SF₆ 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 SF₆ 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 SF₆

Electric power equipments filled with SF₆ are stored and transported according to local and international regulations.

4.4 Responsibilities

The owner of the electric power equipment utilising SF₆ is responsible for the proper use, transportation, and disposal of the equipment and the gas. He is also responsible for record-keeping regarding SF₆ 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 SF₆ electric power equipment.

Table 4 – Measures when working with SF₆ 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 SF₆ 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 SF₆:

- 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

SF₆ 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 SF₆ 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-arc'd 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 SF₆ 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 3 10 (NOTE 3) 10-14 (NOTE 3) 3	Not applicable Wash Not applicable 1 Not applicable	24 Not applicable 0,25 48 Not applicable	[3] [2] [4] [5] [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 O₂ or the amount of by-products are at unsafe levels, a respirator is used according to local regulations (for example European Standard EN 136);
- O₂ concentration measurement device for permanent monitoring the O₂ 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 SF₆ 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 SF₆ due to external fire or internal arc fault

General safety recommendations to adopt when working with SF₆ on site are given in the 5.1. The present subclause describes additional safety measures in case of abnormal release of SF₆ 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-arc'd 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 O₂ 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 SF₆, 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 SF₆.

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 SF₆ 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 SF₆ 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 SF₆ filled equipment, independently from the question whether SF₆ handling is involved or not;
- All personnel working with SF₆ filled equipment, independently from the question whether SF₆ handling is involved or not.

No prerequisites are requested for attending the training.

NOTE All personnel working in the proximity to SF₆ 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 SF₆ emissions and mitigation approaches [12];
- Physical, chemical and environmental characteristics of SF₆ (see Annex A);
- Use of SF₆ 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 SF₆ quality on-site;
- Perform a SF₆ 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;
- SF₆ quality according to IEC 60376 (technical grade SF₆) and IEC 60480 (SF₆ 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 SF₆ filled compartments (see 3.10, 3.11, 3.12, and 3.13);
- Instruments and procedures for checking the SF₆ 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 SF₆ 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 SF₆ (see Clause 4);
- Monitoring of SF₆ 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 SF₆ filling (see 7.1);
- Procedures for topping-up with SF₆ (see 7.2);
- Procedures for recovery and reclaiming of non-arced SF₆ (see 9.1);
- SF₆ 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 SF₆, 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 SF₆ due to fire or internal arc fault (see 5.2);
- Procedures for recovery and reclaiming of normally and heavily arced SF₆ (see 9.1 and 9.2);
- SF₆ 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 SF₆ 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 SF₆ recovery);
- Restrict task performance (for example SF₆ 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 SF₆ handling during installation and commissioning

This clause provides guidance for working with technical grade SF₆, according to IEC 60376 or used SF₆ 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 SF₆ quality after filling

This subclause applies to switchgear compartments of pressure systems that currently contain a gas different from SF₆ (typically air or N₂) 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/N₂ evacuation and SF₆ filling in each compartment is performed according to Figure 1. Additional details are in Table 3.