BS EN 62271-4:2013

BSI Standards Publication

# High-voltage switchgear and controlgear

## Part 4: Handling procedures for sulphur hexafluoride ($SF_6$) and its mixtures

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## National foreword

This British Standard is the UK implementation of EN 62271-4:2013. It is identical to IEC 62271-4:2013. It supersedes PD CLC/TR 62271-303:2009, which will be withdrawn on 30 September 2016.

The UK participation in its preparation was entrusted by Technical Committee PEL/17, Switchgear, controlgear, and HV-LV co-ordination, to Subcommittee PEL/17/1, High-voltage switchgear and controlgear.

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

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Published by BSI Standards Limited 2013

ISBN 978 0 580 69838 5
ICS 29.130.10; 29.130.99

**Compliance with a British Standard cannot confer immunity from legal obligations.**

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 November 2013.

### Amendments/corrigenda issued since publication

| Date | Text affected |
|---|---|

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

**EN 62271-4**

November 2013

ICS 29.130.10; 29.130.99

Supersedes CLC/TR 62271-303:2009

English version

# High-voltage switchgear and controlgear - Part 4: Handling procedures for sulphur hexafluoride ($SF_6$) and its mixtures

(IEC 62271-4:2013)

Appareillage à haute tension -
Partie 4: Utilisation et manipulation de l'hexafluorure de soufre ($SF_6$) et des mélanges contenant du $SF_6$
(CEI 62271-4:2013)

Hochspannungs-Schaltgeräte und -Schaltanlagen -
Teil 4: Handhabungsmethoden im Umgang mit Schwefelhexafluorid ($SF_6$) und seinen Mischgasen
(IEC 62271-4:2013)

This European Standard was approved by CENELEC on 2013-09-30. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CENELEC member.

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CENELEC
European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

**CEN-CENELEC Management Centre: Avenue Marnix 17, B - 1000 Brussels**

## Foreword

The text of document 17A/1044/FDIS, future edition 1 of IEC 62271-4, prepared by SC 17A “High-voltage switchgear and controlgear” of IEC/TC 17 “Switchgear and controlgear" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 62271-4:2013.

The following dates are fixed:

| | | |
|---|---|---|
| • latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement | (dop) | 2014-06-30 |
| • latest date by which the national standards conflicting with the document have to be withdrawn | (dow) | 2016-09-30 |

This document supersedes CLC/TR 62271-303:2009.

EN 62271-4:2013 includes the following significant technical changes with respect to CLC/TR 62271-303:2009:

a) the description of the potential effects on health of $SF_6$ by-products (former Annex D of CLC/TR 62271-303:2009) has been replaced by the calculation methods for evaluating of the potential effects on health of $SF_6$ by-products (see Annex H);

b) information about cryogenic reclaim of $SF_6$ have been added (see Annex I);

c) handling procedures for the most popular $SF_6$ mixtures have been added (see Annex J).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC [and/or CEN] shall not be held responsible for identifying any or all such patent rights.

## Endorsement notice

The text of the International Standard IEC 62271-4:2013 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

| | | |
|---|---|---|
| IEC 62271-203:2011 | NOTE | Harmonized as EN 62271-203:2012 (not modified). |
| ISO 14040:2006 | NOTE | Harmonized as EN ISO 14040:2006 (not modified). |

# Annex ZA
(normative)

## Normative references to international publications with their corresponding European publications

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE When 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 | - | International Electrotechnical Vocabulary (IEV) - Chapter 441: Switchgear, controlgear and fuses | - | - |
| IEC 60050-601 | - | International Electrotechnical Vocabulary (IEV) - Chapter 601: Generation, transmission and distribution of electricity - General | - | - |
| IEC 60376 | - | Specification of technical grade sulfur hexafluoride ($SF_6$) for use in electrical equipment | EN 60376 | - |
| IEC 60480 | - | Guidelines for the checking and treatment of sulphur hexafluoride ($SF_6$) taken from electrical equipment and specification for its re-use | EN 60480 | - |
| IEC 62271-1 | - | High-voltage switchgear and controlgear - Part 1: Common specifications | EN 62271-1 | - |
| - | - | Transportable gas cylinders - Gas cylinder identification (excluding LPG) - Part 3: Colour coding | EN 1089-3 | - |

# CONTENTS

# INTRODUCTION

As agreed with TC 10, annexes A, E, F, G, H and I will be removed from this document as soon as the revised editions of IEC 60376 and IEC 60480 have been published.

# HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

# Part 4: Handling procedures for sulphur hexafluoride ($SF_6$) and its mixtures

## 1 General

### 1.1 Scope

This part of IEC 62271 applies to the procedures for handling of $SF_6$ during installation, commissioning, normal and abnormal operations, disposal at the end-of-life of high-voltage switchgear and controlgear.

These procedures are regarded as minimum requirements to ensure the safety of personnel working with $SF_6$ (see Annex B) and to minimize the $SF_6$ emission to the environment.

This standard generally applies also to gas mixtures containing $SF_6$. The particularities for their handling are covered in Annex J.

NOTE 1 Throughout this standard, use of the term High-Voltage (refer to IEC 60050-601:1985, 601-01-27) means a rated voltage above 1 000 V. However the term Medium Voltage (refer to IEC 60050-601: 1985, 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 standard, the term “electric power equipment” stands for “high-voltage and medium-voltage switchgear and controlgear”.

NOTE 3 Throughout this standard, the term “pressure” stands for “absolute pressure”.

### 1.2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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 – Chapter 441: Switchgear, controlgear and fuses*

IEC 60050-601, *International Electrotechnical Vocabulary – Chapter 601: Generation, transmission and distribution of electricity – General*

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 re-use*

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

EN 1089-3, *Transportable gas cylinders. Gas cylinder identification (excluding LPG). Colour coding*

## 2 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-441 and IEC 60050-601, as well as the following apply.

### 2.1
**abnormal release of $SF_6$**
release from equipment in service due to a failure in the pressure system or mistake in the handling process

Note 1 to entry: An abnormal $SF_6$ leak is usually an unwanted and continuous emission of gas at a higher rate than the equipment designed leak rate. As soon as an abnormal $SF_6$ leak is detected, appropriate measures to locate and eliminate it should be arranged.

### 2.2
**handling of $SF_6$**
any process which might involve transfer of $SF_6$

### 2.3
**evacuation**
transfer of a gas different from $SF_6$ (e.g. air or $N_2$) which can be released into the atmosphere. The operation is performed utilising a vacuum pump

### 2.4
**recovery of $SF_6$**
transfer of $SF_6$ from the gas compartment into a reclaimer or storage container

Note 1 to entry: The operation is normally performed utilising a recovery compressor.

### 2.5
**topping-up with $SF_6$**
filling a pre-filled compartment with $SF_6$ to the rated filling pressure

Note 1 to entry: 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.

### 2.6
**re-filling with $SF_6$**
filling a compartment with $SF_6$ to the rated filling pressure to assure continuity of service

### 2.7
**reclaim of $SF_6$**
a series of $SF_6$ handling procedures including recovery and minimum $SF_6$ refining process such as filtering dust, by-products, moisture, oil, etc.

Note 1 to entry: A standard reclaimer is described in Annex D; while a cryogenic reclaimer is described in Annex I.

Note 2 to entry: Sometimes the words “reclaiming” or “reclamation” may be used with the same meaning as “reclaim”.

### 2.8
**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 1 to entry: This term generally applies to high-voltage switchgear and controlgear.

[SOURCE: IEC 60050-441: 1984, 441-12-05]

**2.9**
**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 to entry: Several gas-filled compartments may be permanently interconnected to form a common gas-system (gas-tight assembly).

Note 2 to entry: The definition is the same as in IEC 62271-1.

**2.10**
**controlled pressure system for gas**
volume which is automatically replenished from an external compressed gas supply or internal gas source

Note 1 to entry: Examples of controlled pressure systems are air-blast circuit-breakers or pneumatic operating mechanisms.

Note 2 to entry: A volume may consist of several permanently connected gas-filled compartments.

Note 3 to entry: The definition is the same as in IEC 62271-1.

**2.11**
**closed pressure system for gas**
volume which is replenished only periodically by manual connection to an external gas source

Note 1 to entry: Example of closed pressure systems are $SF_6$ single pressure circuit-breakers.

Note 2 to entry: The definition is the same as in IEC 62271-1.

**2.12**
**sealed pressure system**
volume for which no further gas or vacuum processing is required during its expected operating life

Note 1 to entry: Examples of sealed pressure systems are tubes of vacuum circuit-breakers or some $SF_6$ circuit-breakers.

Note 2 to entry: Sealed pressure systems are completely assembled and tested in the factory.

Note 3 to entry: The definition is the same as in IEC 62271-1.

**2.13**
**technical grade $SF_6$**
$SF_6$ gas having a very low level of impurities in accordance with IEC 60376

**2.14**
**used $SF_6$**
gas removed from an item of electrical equipment, initially filled with $SF_6$ according to IEC 60376 or IEC 60480

Note 1 to entry: If after filling, the gas is removed for any purpose during the life of the equipment, e.g. repair, service, maintenance, the gas will be transferred and is considered as used gas.

Note 2 to entry: Annex G provides information regarding the by-products of used $SF_6$, which occur in both gaseous and solid form.

**2.15**
**used $SF_6$ suitable for reuse on site**
used $SF_6$ having a maximum impurity level in accordance with IEC 60480

Note 1 to entry: If necessary, service units with appropriate filters and adsorber materials should be used.

### 2.16

**used $SF_6$ suitable for reuse at the gas manufacturer**

used $SF_6$ exceeding the maximum acceptable impurity level stated in IEC 60480, suitable for reuse by the gas manufacturer

Note 1 to entry: If necessary to meet the specification, service units with appropriate filters and adsorber materials should be used.

### 2.17

**used $SF_6$ not suitable for reuse**

used $SF_6$ not falling under the category defined under 2.15 or 2.16

Note 1 to entry: Used $SF_6$ not suitable for reuse is disposed according to local or international regulations on waste management.

### 2.18

**non-arced $SF_6$**

used $SF_6$ having less than approximately 1 ml/l (0,1 % by volume) of gaseous by-products

Note 1 to entry: Non-arced $SF_6$ is typically expected to be in any compartment after filling and prior to energising or after insulation testing or in insulation compartments which never experienced arcing.

### 2.19

**normally arced $SF_6$**

used $SF_6$ having between approximately 1 ml/l (0,1 % by volume) and approximately 10 ml/l (1 % by volume) of gaseous by-products.

Note 1 to entry: Normally arced $SF_6$ is typically expected to be in circuit breakers or switches after normal (load or fault) operations.

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

### 2.20

**heavily arced $SF_6$**

used $SF_6$ having more than approximately 10 ml/l (1 % by volume.) of gaseous by-products

Note 1 to entry: Heavily arced $SF_6$ is typically expected to be in any gas compartments after internal arc fault or circuit breakers or switches after interruption failure or circuit breakers after successful interruptions of several short circuits at high amplitude in relation with its ratings.

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

### 2.21

**$SF_6$ mixture**

gas mixture formed by $SF_6$ and a complementary gas, typically $N_2$ or $CF_4$

## 3 $SF_6$ handling during installation and commissioning

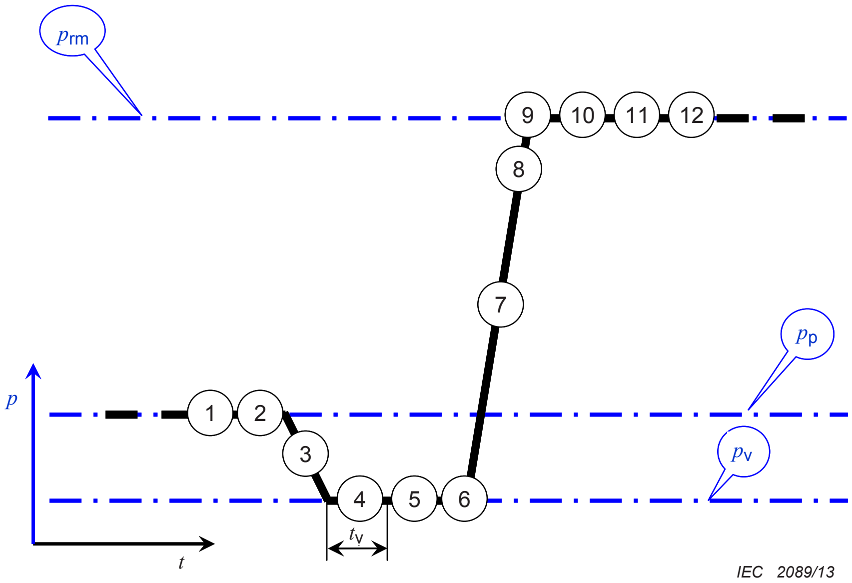
### 3.1 General

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 controlgear has been installed on site.

### 3.2 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 slight overpressure (typically 0,1 MPa to 0,15 MPa).

The following detailed sequence of operations for air/$N_2$ evacuation and $SF_6$ filling in each compartment shall be performed according to Figure 1 and Table 1, except as otherwise specified in the handling procedure detailed by the Original Equipment Manufacturer in the Operating Instruction Manual.



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| | |
|---|---|
| 1 | Prepare $SF_6$ handling equipment |
| 2 | Adsorber installation |
| 3 | Evacuation |
| 4 | Vacuum stabilisation phase |
| 5 | Vacuum holding phase (optional step) |
| 6 | Documentation |
| 7 | Filling with $SF_6$ |
| 8 | Documentation |
| 9 | Pressure/density sensor inspection |
| 10 | Tightness inspection |
| 11 | $SF_6$ quality checking |
| 12 | Documentation |
| $p_{rm}$ | $SF_6$ rated filling pressure |
| $p_p$ | Initial pressure in the gas compartment |
| $p_v$ | Evacuation pressure $< 2$ kPa |
| $t_v$ | Vacuum stabilisation time $\geq 30$ min |

**Figure 1 – Evacuation, filling and checking the $SF_6$ quality after filling**

**Table 1 – Evacuation, filling and checking the $SF_6$ quality after filling**

| Step | | Procedure |
|---|---|---|
| 1 | Prepare $SF_6$ handling equipment | Check that the $SF_6$ handling equipment 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 to reach 2 kPa. |
| 4 | Vacuum stabilisation phase | Leave the vacuum pump running for at least 30 min and then disconnect the vacuum pump by closing the valve. Read the pressure gauge. [a] |
| 5 | Vacuum holding phase (optional step) | The pressure in the compartment should remain lower than 2 kPa for the time which may be required by the Original Equipment Manufacturer in the Operating Instruction Manual]. |
| 6 | Documentation | Record at least the manufacturer, equipment type reference, serial number and compartment reference to identify the gas compartment, the evacuation pressure (i.e. the residual air content), ambient temperature and date for further reference. |
| 7 | 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, a regulator to allow a good control of the filling process and a calibrated gauge to avoid overfilling.[b c] |
| 8 | Documentation | Record at least the manufacturer and serial number to identify the gas compartment, the final filling pressure, ambient temperature and date for further reference. |
| 9 | Pressure/density sensor inspection | Check the functionality of the pressure/density sensor. The operation can be performed during the filling operation and shall not be considered as a calibration. |
| 10 | 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. |
| 11 | $SF_6$ 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.[d] |
| 12 | Documentation | Record at least the manufacturer and serial number to identify the gas compartment, the functionality of the pressure/density sensor, the moisture content, the $SF_6$ content, ambient temperature and date for further reference. |

[a] The vacuum duration can be prolonged in order to better remove moisture when for example the ambient temperature is freezing, except as otherwise specified by the Original Equipment Manufacturer in the Operating Instruction Manual.

[b] $SF_6$ to be introduced into the gas compartment may be either technical grade $SF_6$ or used $SF_6$ suitable for reuse on site.

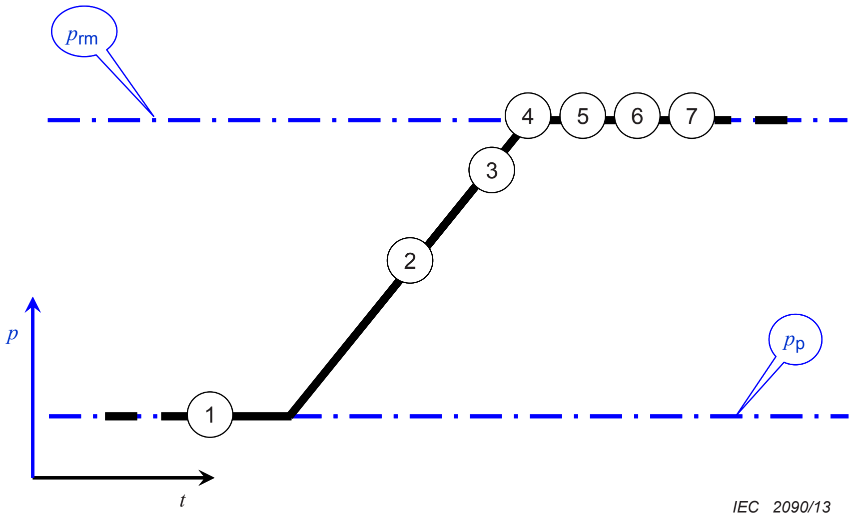
[c] No $SF_6$ check is required if the gas comes from the supplier in sealed containers, or if the gas is stored in sealed containers with an appropriate label or certificate to guarantee the gas is suitable for reuse. In all other cases, the $SF_6$ quality may be checked prior to the filling operation (see 4.2).

[d] If the gas compartment has a small volume, re-filling after $SF_6$ quality checking may be required.

### 3.3 Topping-up of $SF_6$ pre-filled compartments to the rated filling 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.

The following detailed sequence of operations for $SF_6$ topping-up in each pre-filled compartment shall be performed according to Figure 2 and Table 2, except as otherwise specified in the handling procedure detailed by the Original Equipment Manufacturer in the Operating Instruction Manual.



| | |
|---|---|
| 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 |
| $p_{rm}$ | $SF_6$ 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 filling pressure/density**

**Table 2 – Topping-up of $SF_6$ pre-filled compartments to the rated filling 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, a regulator to allow a good control of the filling process and a calibrated gauge to avoid overfilling.[a] [b] |
| 3 | Documentation | Record at least the manufacturer, equipment reference, serial number and compartment reference to identify 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 and shall not be considered as a calibration. |
| 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.[c] |
| 7 | Documentation | Record at least the manufacturer and serial number to identify the gas compartment, the functionality of the pressure/density sensor, the moisture content, the $SF_6$ content, ambient temperature and date for further reference. |

[a] $SF_6$ to be introduced into the gas compartment may be either technical grade $SF_6$ or used $SF_6$ suitable for reuse on site.

[b] 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 may be checked prior to the filling operation (see 4.2).

[c] If the gas compartment has a small volume, re-filling after $SF_6$ quality checking may be required.

### 3.4 Filling sealed pressure systems

The large majority of medium-voltage switchgear and controlgear uses sealed pressure systems, as defined in 2.12. 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.

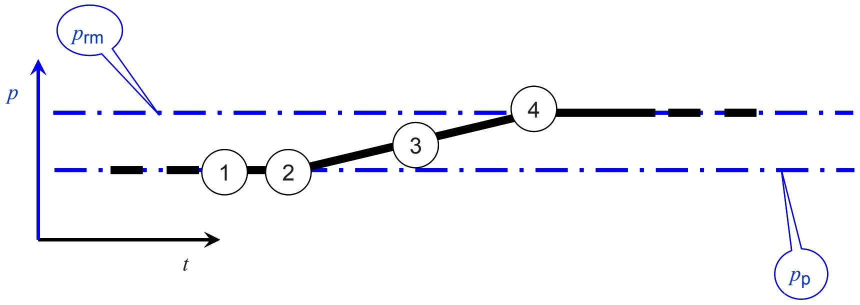
Under some abnormal circumstances (e.g. in case of damage) it may be required to re-fill or re-commission the equipment on-site. The Original Equipment Manufacturer should be contacted for this purpose.

## 4 $SF_6$ handling during normal service life

### 4.1 Re-filling of $SF_6$ to the rated filling 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 shall be immediately arranged.

The following detailed sequence of operations for $SF_6$ re-filling in each compartment shall be performed according to Figure 3 and Table 3 except as otherwise specified in the handling procedure detailed by the Original Equipment Manufacturer in the Operating Instruction Manual.



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| | | | |
|---|---|---|---|
| 1 | Identify the nature of the leak | 4 | Documentation |
| 2 | Prepare $SF_6$ handling equipment | $p_{rm}$ | $SF_6$ 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 rated filling pressure/density**

**Table 3 – $SF_6$ re-filling to the rated filling 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 the compartment until the $SF_6$ rated filling pressure is reached. Use a safety valve, a regulator to allow a good control of the filling process and a calibrated gauge to avoid overfilling. [a] [b] |
| 4 | Documentation | Record at least the manufacturer, equipment type reference, serial number and compartment reference to identify the gas compartment, the final filling pressure, ambient temperature and date for further reference. |

[a] $SF_6$ to be introduced into the gas compartment may be either technical grade $SF_6$ or used $SF_6$ suitable for reuse on site.

[b] 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.

## 4.2 Checking the $SF_6$ quality

### 4.2.1 General

The measurement of the $SF_6$ quality is usually done on-site, using portable equipment. Off-site analysis may exceptionally be performed to cross-check 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 (e.g. water content in mg/kg), $SF_6$ percentage, and total reactive gaseous by-products giving rise to residual acidity content (e.g. total amount of reactive gasses in µl/l).

NOTE Adequate corrections for measurements made at other temperatures than 20 °C are specified by the Original Equipment Manufacturer in the Operating Instruction Manual.

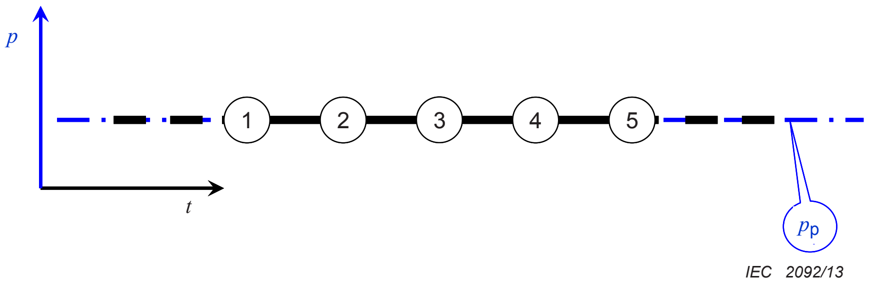
The total reactive gaseous by-products shall be checked first to prevent damage of other portable equipment, if the history of the gas-filled compartment is unknown.

### 4.2.2 Measurement of the $SF_6$ quality with portable equipment

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

The following detailed sequence of operations for an on-site $SF_6$ quality check shall be performed according to Figure 4 and Table 4, except as otherwise specified in the handling procedure detailed by the Original Equipment Manufacturer in the Operating Instruction Manual.

Characteristics of portable equipment are described in Annex D.



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

**Figure 4 – Checking the $SF_6$ quality on-site**

**Table 4 – Checking the $SF_6$ quality on-site**

| **Step** | | **Procedure** |
|---|---|---|
| 1 | Prepare portable equipment | Check that the portable equipment is working properly, the ambient conditions are within the working range, e.g. temperature,[a] 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.[b] |
| 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. [c] |
| 5 | Documentation | Record at least the manufacturer, equipment type reference, serial number and compartment reference to identify the gas compartment, the reading and the date for further reference. |

[a] Typical temperature ranges for portable equipment are given in Table D.2.

[b] Sampled $SF_6$ should be recovered or pumped back into the gas filled compartment.

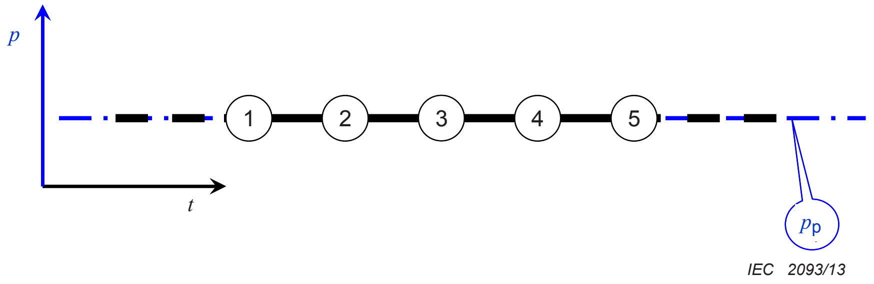
[c] If the gas compartment has a small volume, re-filling after $SF_6$ quality checking may be required.

### 4.2.3 Sampling and shipment of $SF_6$ for off-site analysis

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

The following detailed sequence of operations for $SF_6$ sampling and shipment shall be performed according to Figure 5 and Table 5 except as otherwise specified in the handling procedure detailed by the Original Equipment Manufacturer in the Operating Instruction Manual.

Characteristics of cylinders for $SF_6$ samples are described in Annex D.



| | | | |
|---|---|---|---|
| 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 5 – $SF_6$ sampling and shipment**

| Step | | Procedure |
|---|---|---|
| 1 | Prepare $SF_6$ sampling equipment | Evacuate the sampling cylinder.[a] 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 and keep a record: the manufacturer, equipment type reference, serial number and compartment reference to identify the gas compartment, The $SF_6$ pressure, ambient temperature and date for further reference. |
| 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.[b] |
| 5 | Shipment | Transportation to the laboratory is done in accordance to local and international regulations, as described in Annex A. |

[a] Clause D.7 describes cylinders suitable for gas sampling.

[b] If the gas compartment has a small volume, re-filling after $SF_6$ quality checking may be required.

# 5 $SF_6$ recovery and reclaim during maintenance

## 5.1 General

This clause contains the procedures for $SF_6$ recovery and reclaim from any gas-filled compartment during maintenance.

Once $SF_6$ has been recovered and reclaimed, it can be either reused on site, stored or transported off site for further reuse or disposal, according to IEC 60480.

## 5.2 $SF_6$ recovery and reclaim from any compartment of controlled or closed pressure systems containing non-arced or normally arced $SF_6$

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

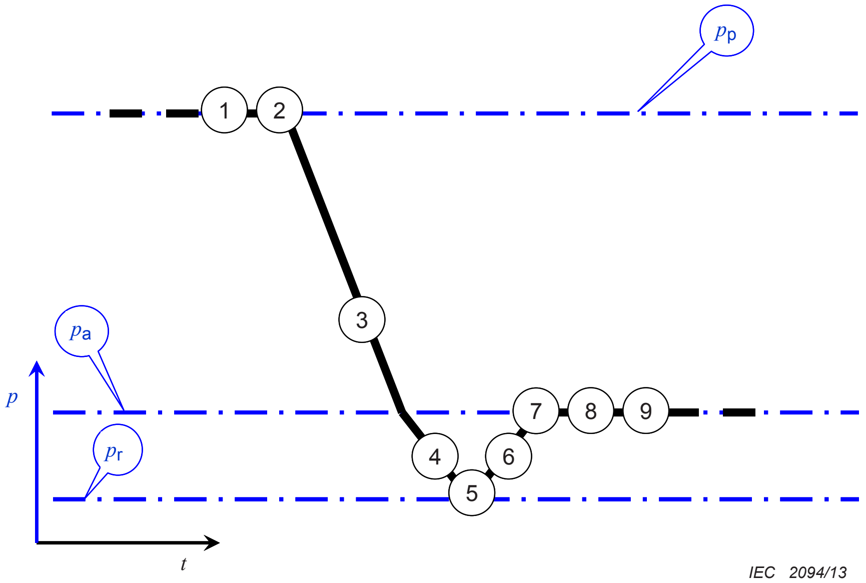
The partial $SF_6$ pressure in the gas compartment prior to flooding with (dry) air and opening shall be lower than 2 kPa.

Figure 6 and Table 6 can be adopted as an example of the detailed sequence of operations for $SF_6$ recovery and reclaim from any compartment of controlled or closed pressure systems containing non-arced or normally arced $SF_6$, except as otherwise specified in the handling procedure detailed by the Original Equipment Manufacturer in the Operating Instruction Manual.

There are cases where the $SF_6$ residual pressure of 2 kPa cannot be reached using the procedure given in Figure 6 and Table 6, despite the use of adequate recovery facilities (e.g. due to leakage of the switchgear, small pumping apertures in the switchgear). In such cases other methods may be applied to reach the partial $SF_6$ pressure of 2 kPa (e.g. dilution method) in the gas compartment prior to opening.

NOTE The partial $SF_6$ pressure is the pressure of $SF_6$ occupying alone the whole volume of the gas compartment. For pure $SF_6$ if the procedure detailed in Figure 6 and Table 6 is followed, $SF_6$ is the only gas in the gas compartment and therefore the partial $SF_6$ pressure is practically equal to the $SF_6$ residual pressure.

The safety rules given in Annex B should be followed.



1 Prepare $SF_6$ handling equipment

2 Connect external pre-filters (optional step)

3 $SF_6$ recovery

4 Minimise residual $SF_6$ content

5 Documentation

6 Flood with (dry) air

7 Open the gas compartment

8 Remove solid by-products and adsorbers when present

9 Neutralisation, if required

$p_p$ $SF_6$ pressure in the gas-filled compartment

$p_a$ Atmospheric pressure

$p_r$ $SF_6$ residual pressure < 2 kPa

**Figure 6 – Example of recovery and reclaim from any compartment of controlled or closed pressure systems containing non-arced or normally arced $SF_6$**

## Table 6 – Example of recovery and reclaim from any compartment of controlled or closed pressure systems containing non-arced or normally arced $SF_6$

| Step | | Procedure |
|---|---|---|
| 1 | Prepare $SF_6$ handling equipment | Check that the $SF_6$ handling equipment is properly working, the filters and pre-filters are still active and connected, and the gas connections are clean and dry, hoses are evacuated and no leaks on connection fittings exist to avoid contamination. Check the capacity and the condition of the storage containers are compatible with the gas compartments to be reclaimed. Check the validity of the calibration of instruments subject to calibration. |
| 2 | Connect external pre-filters (optional step) | Connect one or multiple external pre-filters between the gas-filled compartment and the inlet of the $SF_6$ handling equipment. |
| 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.[a] |
| 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, equipment type reference, serial number and compartment reference to identify the gas compartment, the $SF_6$ residual pressure $p_r$, the $SF_6$ residual quantity, ambient temperature and the date for further reference. |
| 6 | Flood with (dry) air | Disconnect the compressor and let the air enter slowly into the gas compartment.[b] |
| 7 | Open the gas compartment | Apply safety rules according to Annex B. Carefully open the gas compartment. |
| 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 Annex B. |

[a] In 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.

[b] Dry air or $N_2$ from the bottle may be introduced in the compartment to reduce moisture contamination.

### 5.3 Recovery and reclaim from any compartment of controlled or closed pressure systems containing heavily arced $SF_6$

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

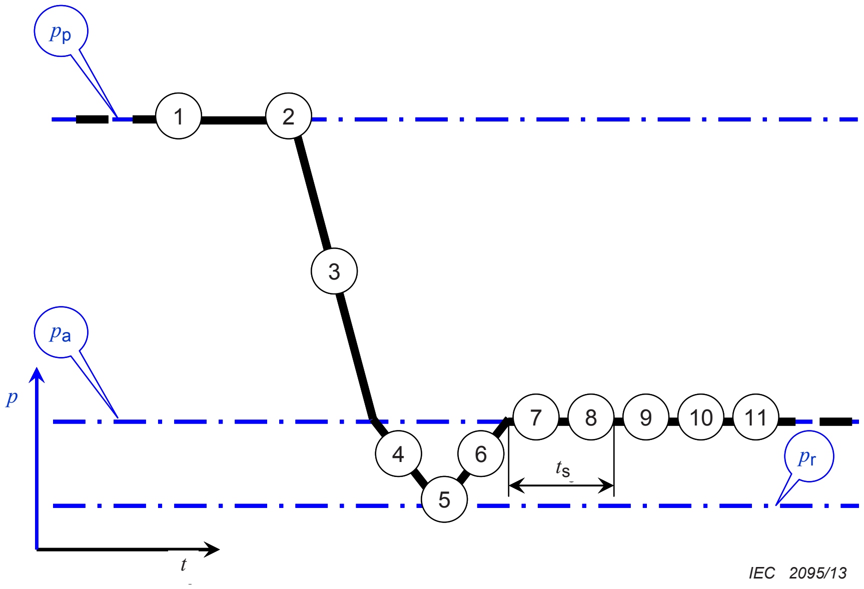
The partial $SF_6$ pressure in the gas compartment prior to flooding with (dry) air and opening shall be lower than 2 kPa.

Figure 7 and Table 7 can be adopted as an example of the detailed sequence of operations for $SF_6$ recovery and reclaim from any compartment of controlled or closed pressure systems containing heavily arced $SF_6$ except as otherwise specified in the handling procedure detailed by the Original Equipment Manufacturer in the Operating Instruction Manual.

There are cases where the $SF_6$ residual pressure of 2 kPa cannot be reached using the procedure given in Figure 7 and Table 7, despite the use of adequate recovery facilities (e.g. due to leakage of the switchgear, small pumping apertures in the switchgear). In such cases other methods may be applied to reach the partial $SF_6$ pressure of 2 kPa (e.g. dilution method) in the gas compartment prior to opening.

NOTE The partial $SF_6$ pressure is the pressure of $SF_6$ occupying alone the whole volume of the gas compartment. For pure $SF_6$ if the procedure detailed in Figure 7 and Table 7 is followed, $SF_6$ is the only gas in the gas compartment and therefore the partial $SF_6$ pressure is practically equal to the $SF_6$ residual pressure.

The safety rules given in Annex B should be followed.



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

**Figure 7 – Example of recovery and reclaim from any compartment of controlled or closed pressure systems containing heavily arced $SF_6$**

**Table 7 – Example of recovery and reclaim from any compartment of controlled or closed pressure systems containing heavily arced $SF_6$**

| Step | | Procedure |
|---|---|---|
| 1 | Prepare $SF_6$ handling equipment | Check that the $SF_6$ handling equipment is properly working, the filters and pre-filters are still active and connected, and the gas connections are clean and dry, hoses are evacuated and no leaks on connection fittings exist to avoid contamination. Check the capacity and the condition of the storage containers are compatible with the gas compartments to be reclaimed. Check the validity of the calibration of instruments subject to calibration. |
| 2 | Connect external pre-filters | Connect one or multiple external pre-filters in series between the gas-filled compartment and the inlet of the $SF_6$ handling equipment. |
| 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. Use an external storage container and avoid its overfilling.[a] |
| 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, equipment type reference, serial number and compartment reference to identify the gas compartment, the $SF_6$ residual pressure $p_r$, the $SF_6$ residual quantity, ambient temperature and the date for further reference. |
| 6 | Flood with (dry) air | Disconnect the compressor and let the air enter slowly into the gas compartment.[b] |
| 7 | Settling down of solid by-products | Wait at least 1 h to give enough time for the remaining solid by-products to settle down in the gas compartment. |
| 8 | Open the gas compartment | Apply safety rules according to Annex B. Carefully open the gas compartment.[c] |
| 9 | 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. |
| 10 | Neutralisation | Use 10 % by weight soda solution or equivalent to wash and neutralise all parts and then wash with clean water, according to Annex B. |
| 11 | Documentation | Record all relevant information concerning service behaviour. Include some pictures. |

[a] In 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.

[b] Dry air or $N_2$ from the bottle may be introduced in the compartment to reduce moisture contamination.

[c] If the gas compartment is already open to the atmosphere (e.g. due to operation of a rupture disc or enclosure burn-through), the procedure may be followed starting from step 8.

# 6 Dismantling of $SF_6$ electric power equipment at the end-of-life

## 6.1 General

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 / User’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 can also be applicable at maintenance and overhaul.

Dismantling of electric power equipment and related treatment of used $SF_6$, gas compartments, powders, adsorber materials and effluents shall be conducted with due regard to personnel and environmental safety, as described in Annex B.

## 6.2 End-of-life of controlled or closed pressure systems

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

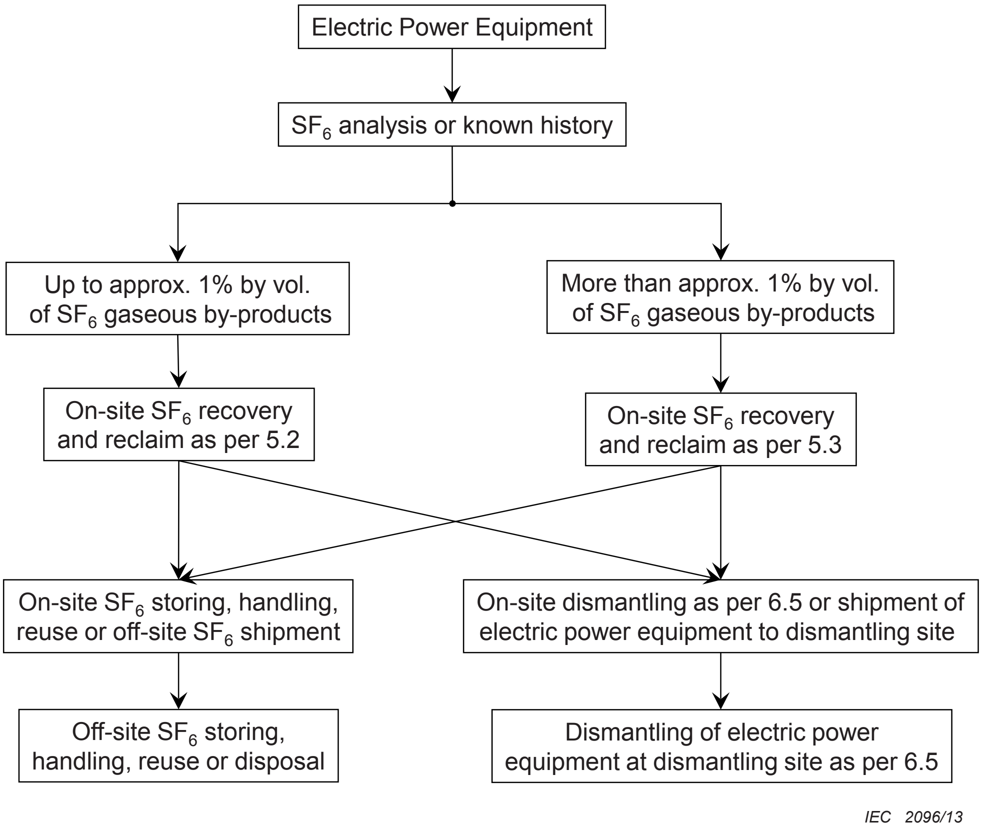


**Figure 8 – End-of-life of controlled or closed pressure systems**

If the past history of a gas-filled compartment is unknown, the gas shall be analysed and handled in safe conditions according to Clause 5. Once $SF_6$ has been recovered and reclaimed, it can be either reused on-site, or stored or transported off-site for further reuse or disposal, according to Annex A. The electric power equipment can be either dismantled on-site or shipped to a dismantling site.

## 6.3 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 dismantling could be performed on-site. The procedure for $SF_6$ recovery remains the same and is reported in 6.4.

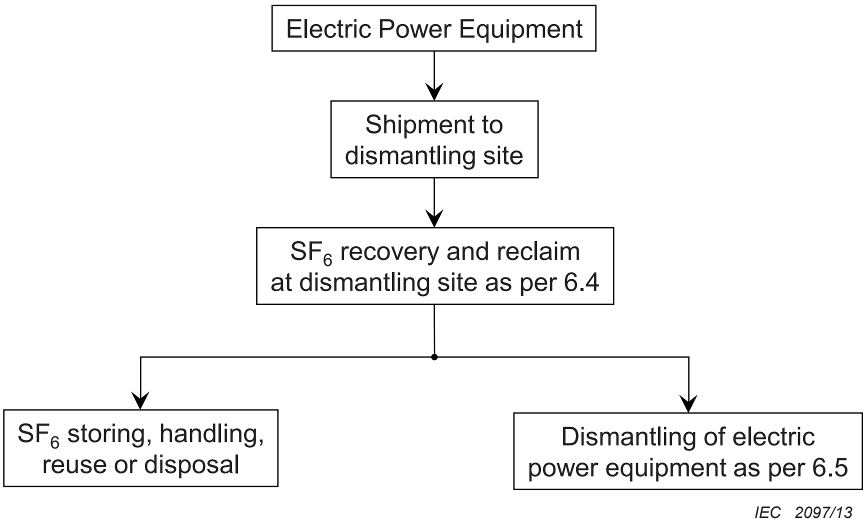


**Figure 9 – End-of-life of sealed pressure systems**

Sealed pressure systems may be shipped to the dismantling site before removal of $SF_6$, this operation being typically conducted by service companies. These companies shall 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.

### 6.4 $SF_6$ recovery and reclaim at the end-of-life of sealed pressure systems

$SF_6$ recovery and reclaim at the end-of-life of any sealed pressure systems may be performed at the dismantling site. When sealed pressure systems are fitted with connecting facilities, dedicated tools according to specifications given by the Original Equipment Manufacturer in the Operating Instruction Manual should be used for the $SF_6$ recovery. If not, then tight drilling systems shall be used.

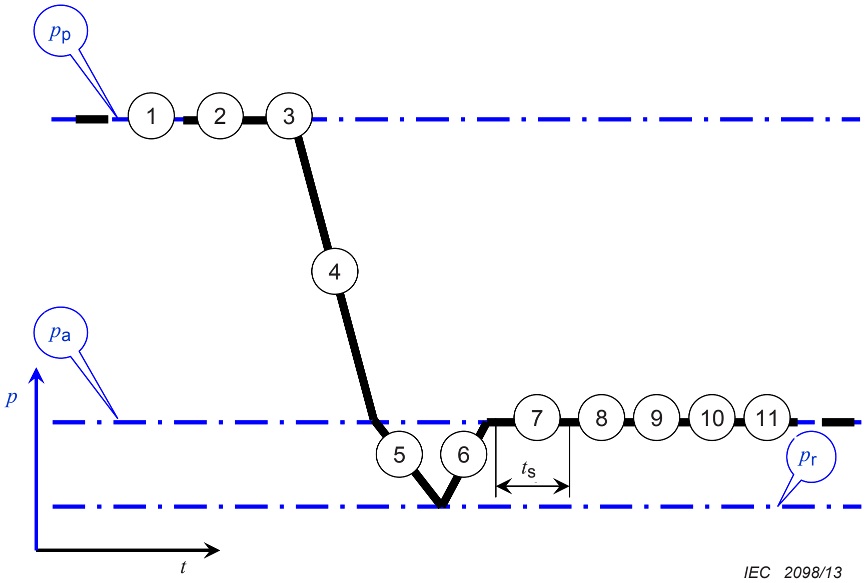
The partial $SF_6$ pressure in the gas compartment prior to opening shall be lower than 2 kPa.

Figure 10 and Table 8 can be adopted as an example of the detailed sequence of operations for $SF_6$ recovery and reclaim at the end-of-life of sealed pressure systems, except as otherwise specified in the handling procedure detailed by the Original Equipment Manufacturer in the Operating Instruction Manual.

There are cases where the $SF_6$ residual pressure of 2 kPa cannot be reached using the procedure given in Figure 10 and Table 8, despite the use of adequate recovery facilities (e.g. due to leakage of the switchgear, small pumping apertures in the switchgear). In such cases other methods may be applied to reach the partial $SF_6$ pressure of 2 kPa (e.g. dilution method) in the gas compartment prior to opening.

NOTE The partial $SF_6$ pressure is the pressure of $SF_6$ occupying alone the whole volume of the gas compartment. For pure $SF_6$ if the procedure detailed in Figure 10 and Table 8 is followed, $SF_6$ is the only gas in the gas compartment and therefore the partial $SF_6$ pressure is practically equal to the $SF_6$ residual pressure.

The safety rules given in Annex B should be followed.



IEC 2098/13

| | |
|---|---|
| 1 | Prepare $SF_6$ handling equipment |
| 2 | Connect external pre-filters, if required |
| 3 | Connect $SF_6$ compartment |
| 4 | $SF_6$ recovery |
| 5 | Minimise residual $SF_6$ content |
| 6 | Flood with air |
| 7 | Settling down of solid by-products, if required |
| 8 | Open the gas compartment |
| 9 | Remove solid by-products, removable parts, and adsorbers when present |
| 10 | Neutralisation, if required |
| 11 | Documentation |
| $p_\mathrm{p}$ | Initial $SF_6$ pressure in the gas-filled compartment |
| $p_\mathrm{a}$ | Atmospheric pressure |
| $p_\mathrm{r}$ | $SF_6$ residual pressure < 2 kPa |
| $t_\mathrm{s}$ | Settling down time ≥ 1 h, if required |

**Figure 10 – $SF_6$ recovery and reclaim at the end-of-life of sealed pressure systems**

**Table 8 – $SF_6$ recovery at the end-of-life of sealed pressure systems**

| Step | | Procedure |
|---|---|---|
| 1 | Prepare $SF_6$ handling equipment | Check that the $SF_6$ handling equipment is working properly, the filters and pre-filters are still active and connected, and the gas connections are clean and dry, hoses are evacuated and no leaks on connection fittings exist to avoid contamination. Check the capacity and the condition of the storage containers are compatible with the gas compartments to be reclaimed. Check the validity of the calibration of instruments subject to calibration. |
| 2 | Connect external pre-filters, if required | Connect one or multiple external pre-filters between the gas-filled compartment and the inlet of the $SF_6$ handling equipment. |
| 3 | 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 shall be used. |
| 4 | $SF_6$ 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 [NOTE]. |
| 5 | Minimise residual $SF_6$ content | Connect the auxiliary compressor stage and leave it running until a pressure lower than 2 kPa is reached. |
| 6 | Flood with air | Disconnect the compressor and let the air enter slowly into the gas compartment. |
| 7 | Settling down of solid by-products, if required. | Wait at least 1 h to give enough time for the remaining solid by-products to settle down in the gas compartment. |
| 8 | Open the gas compartment | Apply safety rules according to Annex B. Carefully open the gas compartment. |
| 9 | 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. |
| 10 | 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 Annex B. |
| 11 | Documentation | Record at least the manufacturer, equipment type reference, serial number and compartment reference to identify the gas compartment, the $SF_6$ residual quantity, ambient temperature and date for further reference. |
| NOTE In 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. | | |

## 6.5 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.

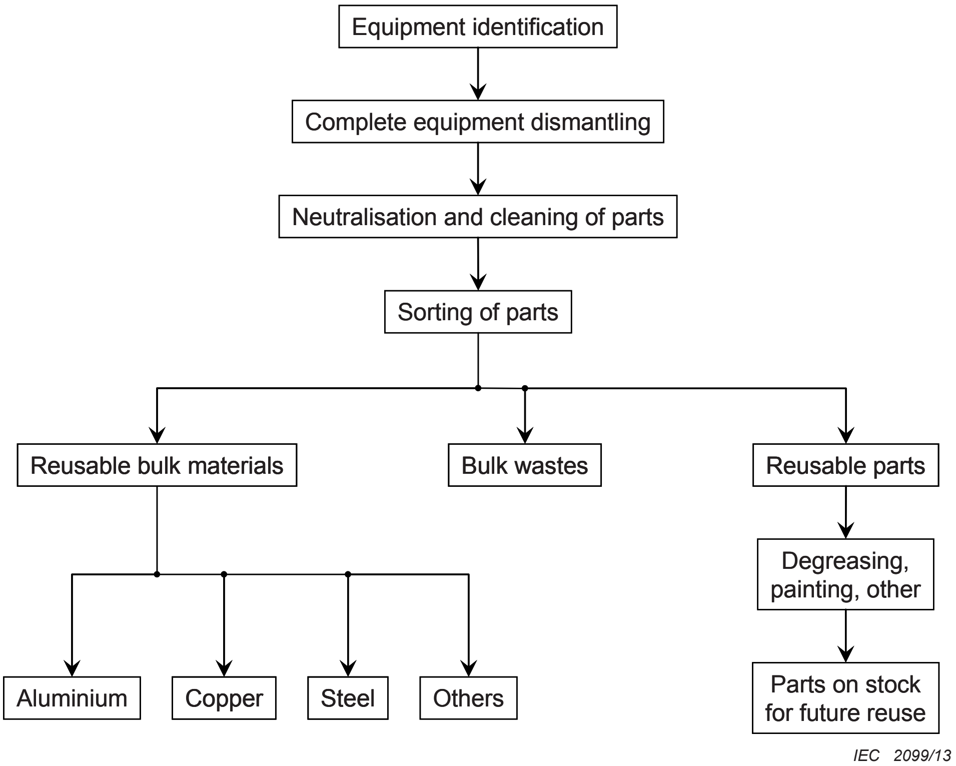


**Figure 11 – Dismantling of electric power equipment**

The first operation consists of 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 Annex B.

For the dismantling phase, operators should know the products. Tools and drawings should be available. The safety rules given in Annex B should be followed.

NOTE A typical item of electric power equipment is made up of approx. 75 % to 90 % by weight of metals (both ferrous and non-ferrous metals), the rest being dielectric material.

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 (e.g. cast resin, plastics, ceramics). The major part of the reclaimable value is in the metals.

### 6.6 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, which has been applied during its life, in relation to the amount of $SF_6$ and the quantity and type of adsorbers. The cumulative arc energy depends on the function and service history of the equipment in question. A load-break switch will 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 G. 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 9.

**Table 9 – 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 ml/l (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 some 10 ml/l (a few percent by volume), light powder deposits |
| Circuit-breakers after successful interruption of several short-circuits at high amplitude or any gas-filled compartment after an internal arcing fault | Heavily arced $SF_6$ | Could exceed 150 ml/l (1 % by volume), medium to heavy powder deposits |

# Annex A
(informative)

# Storage and transportation of $SF_6$

## A.1 General

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

An empty $SF_6$ container can still contain a residual amount of $SF_6$. It shall be stored and transported in the same way as for a filled container.

## A.2 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 should be 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 should be refillable (non-refillable containers should be 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 A.1 gives an overview of all possible storage methods on which a storage container may be based.

**Table A.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 1 000:1 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 shall comply with local and international regulations on pressurised vessels. Container labelling shall also comply with local and international regulations.

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

**Table A.2 – Container types and labelling required for storage and transportation of $SF_6$**

| Gas | Characteristic | Container type | Container labelling [a] |
|---|---|---|---|
| Technical grade $SF_6$ | Liquefied inert gas | **Suitable for liquefied gas up to a pressure of 7 MPa.**<br>NOTE The filling factor for technical grade $SF_6$ is up to 1,04 kg/l.<br>**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<br>**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.**<br>NOTE: Due to the inert gas content (e.g. $N_2$, $O_2$), the filling factor is smaller than 0,8 kg/l. [b]<br>**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 [c]<br>**Danger label 2.2** |
| Used $SF_6$ suitable for reuse at gas manufacturer 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 [f] [g] | |
| | Liquefied gas containing toxic gaseous by-products [d] | Same as for used $SF_6$ suitable for reuse on site [f] [g] | **Stencilled on container:** UN 3162, sulphur hexafluoride, hydrogen fluoride, thionyl fluoride [c]<br>**Danger label 2.3** |
| | Liquefied gas containing both toxic and corrosive gaseous by-products [e] | **Special containers approved for storing and transportation of corrosive gases** (such as hydrofluoric acid HF) with a corrosion-proof valve and adapter [f] [g] | **Stencilled on container:** UN 3308, sulphur hexafluoride, hydrogen fluoride, thionyl fluoride<br>**Danger labels 2.3 + 8** |

[a] UN numbers are assigned 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.

[b] The filling factor is the weight of $SF_6$ contained in the container divided by the container volume and is usually specified in kg/l.

[c] Only the two most abundant contaminants have to be specified.

[d] Any used $SF_6$ containing toxic gaseous by-products can be reclaimed on site to remove the toxic gaseous by-products thereby facilitating easier transportation.

[e] 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.

[f] Containers filled with used $SF_6$ suitable for reuse at gas manufacturer should be tagged with the following sentence: “Contains used $SF_6$ suitable for reuse at gas manufacturer”.

[g] Containers filled with used $SF_6$ not suitable for reuse should be tagged with the following sentence: “Contains used $SF_6$ not suitable for reuse”.

## A.3 Transportation of containers filled with $SF_6$

International regulations for shipment of electric power equipment containing $SF_6$ and $SF_6$ 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 A.3.

**Table A.3 – International regulations for shipment of $SF_6$**

<table>
<tr><th>Gas</th><th>Characteristic</th><th>Class</th><th>Final classification [a]</th><th>Transport document [a]</th></tr>
<tr><td>Technical grade $SF_6$ [b]</td><td>Liquefied inert gas</td><td>2A</td><td>UN 1080 liquefied gas, n.o.s. 2.2</td><td>UN 1080 liquefied gas, n.o.s (sulphur hexafluoride)<br>2.2</td></tr>
<tr><td>Used $SF_6$ suitable for reuse on site</td><td>Liquefied inert gas</td><td>Transportation class and danger label are the same as for technical grade $SF_6$</td><td>UN 3163 liquefied gas, n.o.s. 2.2</td><td>UN 3163 liquefied gas, n.o.s. (sulphur hexafluoride and air or nitrogen or carbon tetrafluoride)<br>2.2</td></tr>
<tr><td rowspan="3">Used $SF_6$ suitable for reuse at gas manufacturer<br>or<br>used $SF_6$ not suitable for reuse</td><td>Liquefied inert gas</td><td colspan="3">UN number, transportation class, danger label, final classification and transport document are the same as for used $SF_6$ suitable for reuse on site</td></tr>
<tr><td>Liquefied toxic gas (gas containing toxic gaseous by-products) [c]</td><td>2T</td><td>UN 3162 liquefied toxic gas, n.o.s. 2.3</td><td>UN 3162 liquefied gas, toxic, n.o.s. (sulphur hexafluoride and hydrogen fluoride and thionyl fluoride<br>2.3</td></tr>
<tr><td>Liquefied toxic and corrosive gas (gas containing both toxic and corrosive gaseous by-products) [d]</td><td>2TC</td><td>UN 3308 liquefied toxic and corrosive gas, n.o.s. 2.3 + 8</td><td>UN 3308 liquefied gas, toxic, corrosive, n.o.s. (sulphur hexafluoride and hydrogen fluoride and thionyl fluoride)<br>2.3 + 8</td></tr>
</table>

[a] UN numbers are assigned 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.

[b] Avoid any contamination of containers dedicated to technical grade $SF_6$.

[c] Any used $SF_6$ containing toxic gaseous by-products can be reclaimed on-site to remove the toxic gaseous by-products thereby facilitating easier transportation.

[d] 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.

## A.4 Storage and transportation of electric power equipment containing $SF_6$

Electric power equipment filled with $SF_6$ shall be stored and transported according to local and international regulations.

## A.5 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 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 in the manuals as per IEC 62271-1.

# Annex B
(informative)

# Safety and first aid

## B.1 General safety rules

### B.1.1 General

Before starting any maintenance/service work in electric power equipment, a detailed inspection of the state of the equipment shall be carried out and documented. In addition to the local safety regulations, at least the following general safety rules shall 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 / User of the equipment and the service provider.

Table B.1 lists the major issues to consider when working with $SF_6$ electric power equipment.

**Table B.1 – Measures when working with $SF_6$ electric power equipment**

| Item | Work in the vicinity of equipment (operation of equipment, visual check, room-cleaning) | Filling, recovery, evacuation of gas compartments | Opening of gas compartments, work on open compartments |
|---|---|---|---|
| Material safety data sheet/operational manuals | Not required | Applicable | Applicable |
| Training | Applicable [a] | 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 |

[a] General information should be specified according to type of work and installation, according to local safety regulations.

A notice stating that open fire, naked flames (e.g. matches), smoking, use of heat engines, heating to more than 200 °C and welding without special precautions are prohibited and instructions for giving first-aid (see B.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 or heavily arced $SF_6$ should:

- use suitable tools and equipment;
- wear suitable protective clothing (see Table B.2 and B.1.5);
- observe high standards of personal hygiene;
- clean themselves and their equipment using disposable materials, before leaving the work area;
- remove protective clothing and wash them 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.

### B.1.2 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 Annex C).

A specific training covering the recovery of used $SF_6$ from a gas-filled compartment is requested for personnel opening or entering the gas compartment. The Operating Instruction Manual of the equipment provided by the Original Equipment Manufacturer should be strictly followed.

Table B.2 gives an overview of the potential risks, safety precautions as well as safety equipment and tools required when opening or entering a gas compartment. No substantial difference between indoor and outdoor conditions is given as the operator opens or enters the compartment.

**Table B.2 – Safety measures when opening 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<br>$O_2$ starvation<br>Remaining used $SF_6$<br>Residual reactive gaseous by-products<br>Solid by-products and adsorber materials | Fumes of cleaning substances<br>$O_2$ starvation<br>Remaining used $SF_6$ or other gas from production process |
| Safety precaution | Removal of solid by-products and adsorber materials<br>Ventilation<br>Measurement of $O_2$ concentration when entering<br>Wear personal protective equipment<br>Protect solid by-products against hydrolysis | Ventilation<br>Measurement of $O_2$ concentration before entering |
| Safety equipment and tools | Suction ventilator or vacuum cleaner<br>$O_2$ concentration measuring device<br>Single use protective overalls, protective footwear, hair cap<br>Acid proof safety gloves<br>Full face mask (preferred) or, at least, breathing protective mask<br>Protective goggles<br>Environmental protection against rain or wind (outdoor only) | Suction ventilator or vacuum cleaner<br>$O_2$ concentration measuring device |

Like any gas but oxygen, a concentration greater than 190 ml/l (19 % by volume) of $SF_6$ in the air is considered as a potential risk of asphyxiation. This is because it reduces the oxygen concentration down to 160 ml/l (16 % by volume), 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 it. In addition to that, the oxygen content in the ambient environment may be checked when working in confined spaces.

Eating, drinking and smoking are prohibited 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.

### B.1.3 Handling of contaminated safety equipment and tools

Equipment and tools, which have been in contact with solid by-products or adsorber materials are considered to be 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 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 B.3.

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

**Table B.3 – Neutralising solutions**

| Active agent | Formula | Concentration kg/100 l | $T_1$ [a] hours | $T_2$ [b] hours | References to the bibliography |
|---|---|---|---|---|---|
| Lime | $Ca(OH)_2$ | Saturated | Not applicable | 24 | [9] |
| Sodium carbonate (washing soda) | $Na_2CO_3$ | 1,1 | Not applicable | 24 | [10] |
| | | 3 | Wash | not applicable | [9] |
| | | 10 [c] | not applicable | 0,25 | [11] |
| | | 10-14 [c] | 1 | 48 | [12] |
| | | 3 | not applicable | not applicable | [13] |
| Sodium bicarbonate | $NaHCO_3$ | 1 [d] | Not applicable | not applicable<br>– | [11] |

[a] 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.

[b] 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.

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

[d] Recommended for washing the skin.

### B.1.4 Pressurised equipment and tools or measuring devices

As with any pressurised gas, a sudden volume expansion results in a local temperature drop and may cause freezing. Suitable insulated gloves (e.g. leather, not latex) 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.

### B.1.5 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 B.2.

Depending on the kind of work to be performed on site and according to Table B.2, workers engaged in handling $SF_6$ are provided with the following personal safety and protective equipment:

- protective gloves: suitable acid resistant gloves made of e.g. neoprene, PVC, rubber;
- protective goggles: chemical type industrial goggles according to local regulations (e.g. 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 (e.g. 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 (e.g. 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 (e.g. European Standard EN 136);
- $O_2$ concentration measurement device for permanent monitoring of the $O_2$ content in the environment;
- environmental protection for outdoor work locations: 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 (e.g. 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.

### B.1.6 Facilities and services

Where gas compartments containing used $SF_6$ have to be recovered 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.

## B.2 Additional safety measures in case of abnormal release of $SF_6$ due to external fire or internal arc

General safety recommendations to adopt when working with $SF_6$ on site are given in B.1. This B.2 describes additional safety measures in case of abnormal release of $SF_6$ due to external fire or internal arc fault.

Under these circumstances, personnel trained on modules C1 or C2 (see clauses C.2.5and C.2.6, respectively) are allowed to enter and clean the switchgear room or to access the electric power equipment. Table B.4 gives an overview of the potential risks, safety precautions as well as safety equipment and tools required.

NOTE Fire fighting can enter the switchgear room in the terms described in the local regulations.

**Table B.4 – 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<br>$O_2$ starvation<br>$SF_6$ abnormally released<br>Residual reactive gaseous by-products<br>Solid by-products | Fumes of cleaning substances<br>$O_2$ starvation<br>$SF_6$ abnormally released |
| Safety precaution | Removal of solid by-products<br>Ventilation<br>Measurement of $O_2$ concentration when entering<br>Wear personal protective equipment | Ventilation<br>Measurement of $O_2$ concentration when entering |
| Safety equipment and tools | Suction ventilator or vacuum cleaner<br>$O_2$ concentration measuring device<br>Single use protective clothes, shoe covers, hair cap<br>Acid proof safety gloves<br>Full face mask (preferred) or, at least, breathing protective mask and protective goggles | Suction ventilator or vacuum cleaner<br>$O_2$ concentration measuring device |

The same rules apply to areas below the level at which the release occurred, poorly ventilated or unventilated areas (e.g. cable trenches, inspection pits, drainage systems). Outdoor equipment needs standard measures for outdoor conditions to be applied (e.g. 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 audible contact should be present, when entering areas which might have a low oxygen concentration.

## B.3 First aid equipment and treatment

### B.3.1 General

First aid equipment includes:

- 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 B.1) should minimise the likelihood of accidents. In case of an accident, first aid treatment should be applied as described in the following clauses.

### B.3.2 Irritation of the skin

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

NOTE While seeking for professional medical advice, the affected part can be treated with calcium gluconate gel (HF antidote gel) as a remedy after washing for fluoride acid on skin.

### B.3.3 Irritation of the eyes

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

### B.3.4 Breathing difficulty

All personnel should immediately evacuate the affected area and move into the fresh air. Contaminated clothing on a person with breathing difficulties should be removed and this person covered with a blanket and kept still and under continuous observation. Emergency medical assistance shall be summoned without delay. If the patient stops breathing, artificial respiration must be immediately commenced by trained and qualified personnel.

# Annex C
(informative)

# Training and certification

## C.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 clauses are focused on training 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 (e.g. development, manufacturing, testing, erection, commissioning, maintenance, repair, 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 of the utmost importance. Training can be done in different locations (e.g. 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 equipment, safety and continuity of service are very important. With the exception of the general training module (module A – awareness, see C.2.2), the scope of the training is related to a specific design (e.g. high-voltage live tank circuit-breaker, medium-voltage switchgear, high-voltage gas insulated switchgear) and different designs require different training to be certified.

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

## C.2 Example of training modules

### C.2.1 General

With respect to the different pressure systems according to definitions given in 2.11 and 2.12, 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 their entire operating life.

Workers handling $SF_6$ shall 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 training is 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 or repair implying gas recovery (e.g. 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.

### C.2.2 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.

All personnel working in the proximity to $SF_6$ filled equipment should be made aware according to the general safety rules given in B.1.

The training covers the following aspects:

- basic knowledge of relevant environmental issues (e.g. climate change, Kyoto Protocol, Global Warming Potential, see Annex F);
- environmental relevance of $SF_6$ emissions and mitigation approaches [19];[1]
- physical, chemical and environmental characteristics of $SF_6$ (see Annex E);
- use of $SF_6$ in electric power equipment;
- existence of local regulations and international standards;
- personnel safety and first aid (e.g. local regulations, emergency plans and instructions in case of e.g. asphyxiation, internal arc fault), (see Annex B);
- $SF_6$ handling, hazards and health characteristics (see E.5)
- design of electric power equipment (properties and application/functionality).

### C.2.3 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.

Personnel should hold a module A certificate to be eligible for module B1 training. Alternatively, a combined training session covering both modules A and B1 is acceptable.

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 reuse);
- the Instruction Manuals given by the Original Equipment Manufacturer in relation to the tasks;
- personnel safety and first aid (e.g. safety equipment required for personal protection), (see Annex B);
- types of $SF_6$ filled compartments (see 2.9, 2.10, 2.11, and 2.12);

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[1] Numbers in square brackets refer to the Bibliography.

- instruments and procedures for checking the $SF_6$ quality (see 4.2 and D.4);
- procedures for re-filling of closed pressure systems (see 4.1 and Annex D);
- leak detection methods and repair techniques;
- categories for $SF_6$ reclaim and reuse (see 2.13, 2.14, 2.15, 2.16, 2.17, 2.18, 2.19, and 2.20);
- storage and transportation of $SF_6$ (see Annex A);
- monitoring of $SF_6$ gas and appropriate recording of data related to local environmental obligations.

### C.2.4 Module B2 – Installation and commissioning

This module provides the second intermediate level of training required for personnel who install and commission electric power equipment on-site.

Personnel should hold a module B1 certificate to be eligible for module B2 training. Alternatively, a combined training session covering both modules A, B1 and B2 is acceptable.

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 (e.g. working on open gas compartments in relation to the task) (see Annex B);
- procedures for air evacuation and $SF_6$ filling (see 3.2);
- procedures for topping-up with $SF_6$ (see 3.3);
- procedures for recovery and reclaim of non-arced $SF_6$ (see 5.2);
- $SF_6$ handling equipment in relation to the tasks (see Annex D).

### C.2.5 Module C1 – Maintenance or repair implying gas recovery

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

- perform maintenance or repair of electric power equipment utilising $SF_6$, including gas recovery, reclaim as well as appropriate handling of by-products;
- provide further extension of the electric power equipment during its operating life.

Personnel should hold a module B1 certificate to be eligible for module C1 training. Alternatively, a combined training session covering both modules A, B1 and C1 is acceptable. 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 (e.g. 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 B.2);
- procedures for recovery and reclaim of normally and heavily arced $SF_6$ (see 5.3);

- $SF_6$ handling equipment in relation to the task (see Annex D);
- procedures for handling, neutralisation and removal of by-products (see B.1.3);
- handling of safety equipment and tools which have been in contact with solid by-products (see B.1.3).

### C.2.6 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 decommission the electric power equipment at the end-of-life.

Personnel should hold a module C1 certificate to be eligible for module C2 training. Alternatively, a combined training session covering both modules A, B1, C1 and C2 is acceptable. 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 A.4);
- dismantling of equipment and part sorting (see Clause 6);
- instructions given by the Original Equipment Manufacturer on the use of tight drilling systems for recovery $SF_6$ from the electric power equipment, if applicable.

## C.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 practical examination sessions are performed to prove the skill and the ability gained. However, any certification required by local regulations takes priority over the present Standard.

Records should be retained so as to:

- record the date on which the training was completed and the training content;
- identify which task and equipment design personnel have been certified for (e.g. $SF_6$ recovery);
- restrict task performance (e.g. $SF_6$ recovery for a certain design) to the personnel who have been certified for (e.g. modules C1 and C2);
- sustain a high level of expertise.

# Annex D
(informative)

# Description of SF$_6$ Handling Equipment

## D.1 General

This annex gives information about minimum functionality and performance criteria for SF$_6$ handling equipment and specific components.

## D.2 Reclaimer

### D.2.1 General

The appropriate type and size of the reclaimer should be chosen according to the SF$_6$ quantity to be handled. Figure D.1 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;
- cylinder to cylinder (or storage tank) transfer.

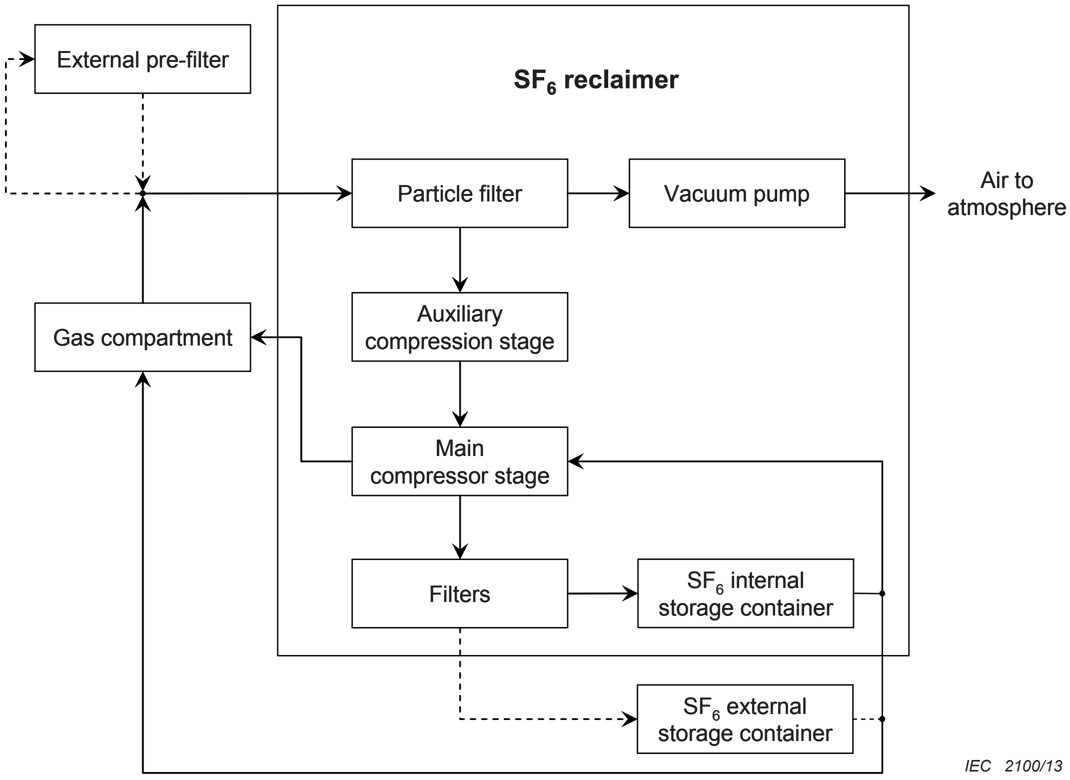


Figure D.1 – General purpose reclaimer

### D.2.2 External pre-filters

An external pre-filter 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. If potential oil contamination of the $SF_6$ is expected (recovering gas from a dual pressure circuit breaker or due to an accidentally contaminated gas compartment) the use of an activated charcoal pre-filter unit is recommended.

Recommended major characteristics are:

- pore size lower than 10 µm (low through-flow resistance);
- residual moisture lower than 200 µl/l;
- residual reactive gaseous by-products lower than 200 µl/l.

### D.2.3 Filters

#### D.2.3.1 General

Filters are required to remove reactive gaseous by-products, moisture and solid particles or oil droplets before storing $SF_6$ in a container, hence allowing for its reuse. These filters are installed in the reclaimer.

Table D.1 shows typical filter types used during $SF_6$ reclaim.

**Table D.1 – Typical filter types used during $SF_6$ reclaim**

| 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 µl/l.<br>Residual $SO_2$+$SOF_2$ lower than 12 µl/l.<br>Particle retention ability. |
| Oil filter | Removes oil when required. | Special filter utilising active charcoal. |

#### D.2.3.2 Particle filter

Some by-products, which are generated during switching operations, are made up of fine solid particles (e.g. 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.

#### D.2.3.3 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 $SF_6$.

#### D.2.3.4 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.

### D.2.4 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 automatically 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 is recommended. If smaller diameters are used, the evacuation process is considerably extended and can hardly be improved by the use of a vacuum pump with higher capacity.

### D.2.5 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 compressor, 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 compressor, 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 are preferred to eliminate the possibility of 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 can be used to speed up $SF_6$ recovery.

### D.2.6 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 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 to be observed. For storage containers with liquid $SF_6$ storage a nominal pressure of 5 MPa is used.

### D.2.7 Evaporator and gas storage container heater

If $SF_6$ is stored in liquid form and used as a gas, thermal losses due to evaporating inside the container can cause $SF_6$ to cool itself to a temperature where it will no longer evaporate. This can usually be observed by a visible frost ring / line on the tank. In order to fill large volumes rapidly, the reclaimers storage vessel(s) should be designed to extract liquid $SF_6$ that is then vaporized inside an evaporator. The evaporator 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.

### D.2.8 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.

### D.2.9 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.

### D.2.10 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.

## D.3 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 synthetic rubber or flexible stainless steel, able to withstand vacuum and permeation are required.

## D.4 Portable devices for gas measurement

### D.4.1 General

Table D.2 gives a survey on gas measuring devices including recommended values for range, operating temperature and minimum accuracy. Those quantities are typically declared by the manufacturer of portable devices for gas measurement in the technical datasheet.

**Table D.2 – Gas measuring devices**

| Device | Measurement | Range | Operating temperature | Minimum accuracy |
|---|---|---|---|---|
| Dew point meter | Moisture | Dew point:<br>-50 °C to 0 °C | -10 °C to 40 °C | ±2 °C |
| $SF_6$ percentage measuring | $SF_6$ percentage $SF_6/N_2$ or $SF_6$/air<br>$SF_6$ percentage $SF_6/CF_4$ | 0 ml/l to 1 000 ml/l | -20 °C to 40 °C | ±10 ml/l<br>±20 ml/l |
| Analysers of reactive gaseous by-products | By-products as e.g. $SO_2$<br>Oil mist | 1 µl/l to 25 µl/l<br>0,16 µl/l to 1,6 µl/l | -10 °C to 40 °C | ±15 % of the full range |
| $SF_6$ pressure gauge | Pressure | 0 MPa to 1 MPa | -20 °C to 40 °C | ±10 kPa |
| Thermometer | Temperature | -25 °C to 70 °C | -25 °C to 70 °C | ±1 °C |

Gas measurements are conventionally referred to and reported at 20 °C. Adequate corrections shall be made for measurements made at other temperatures.

Gas quality measurements can be made under laboratory conditions and on-site. The following clauses 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 total amount of reactive gaseous by-products giving rise to residual acidity content.

State-of-the-art equipment allows for the simultaneous measurement of all contaminant parameters using a single device by taking just one sample and is also capable of pumping back $SF_6$ into the gas compartment.

### D.4.2 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 for this 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 pipes using self-sealing valve connections;
- stainless steel pipes and fittings made of hydrophobic materials e.g. PTFE;
- calibrated or capable of field calibration;
- no $SF_6$ gas release to the environment (e.g. small compressor for gas re-filling 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.

### D.4.3 $SF_6$ 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), 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 $N_2$ or air, or can be calibrated for $SF_6$ / $CF_4$ mixtures.

Desirable characteristics are:

- no $SF_6$ gas release to the environment (e.g. small compressor for gas re-filling 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 volume of $SF_6$ should not be used as different non-reactive gases such as $N_2$ or $CF_4$ may be present.

### D.4.4 Analysers of reactive gaseous by-products

Various methods are available to test for reactive gaseous by-products. Common and recommended practice is to test $SF_6$ for the level of $SO_2$. These tests can be performed using either reactive tubes, (reaction tubes change their initial colour if $SF_6$ containing $SO_2$ is fed through them) or by using an electro-chemical sensor. Electrochemical sensors as well as the $SO_2$ reaction tubes are also sensitive to $SOF_2$.

Desirable characteristics are:

- known sensitivity to $SO_2$ 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 (e.g. small compressor for gas re-filling or make use of an empty cylinder);
- less than ~6 g gas used per measurement.

The use of reaction tubes sensitive to HF is not recommended, as HF reacts very fast with metallic surfaces to form a surface layer of metal fluorides.

## D.5 Portable $SF_6$ detectors

Portable detectors for $SF_6$ are broadly of three types:

- Photo acoustic infrared detectors are based on the pressure waves emitted by the $SF_6$ molecules when illuminated by monochromatic infrared light. Special microphones detect the acoustic signal which is directly proportional to the energy absorbed. Sensitivities down to 0,01 μl/l (10 ppbv) can be achieved which are far superior to other methods. On the other hand, the response time of about 15 s prevents the device being used for leak localisation.
- 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 corona discharge cells which are described below. Sensitivities down to 0,1 μl/l (0,1 ppmv) of $SF_6$ in air can be achieved.
- 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 μl/l (10 ppmv) can be achieved, but not with all available units [14].

Photo acoustic and electron capture detectors are generally used for leak tracing and quantification.

If sensitive enough, corona discharge cells could be suitable for either assessing whether an area contains $SF_6$ or leak detection.

## D.6 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 [15]. 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 μl/l (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.

## D.7 Cylinders for gas samples

Stainless steel cylinders with a volume smaller than 1 l are recommended. The gas quantity should be not smaller than 6 g. The gas should be sampled directly from the container (e.g. 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 should be used.

## D.8 Gas mixing device

Figure D.2 is a gas mixing device which is used to mix $SF_6$ with a complementary gas, typically $N_2$ or $CF_4$, according to a preselected gas ratio during filling or topping-up of electric power equipment.

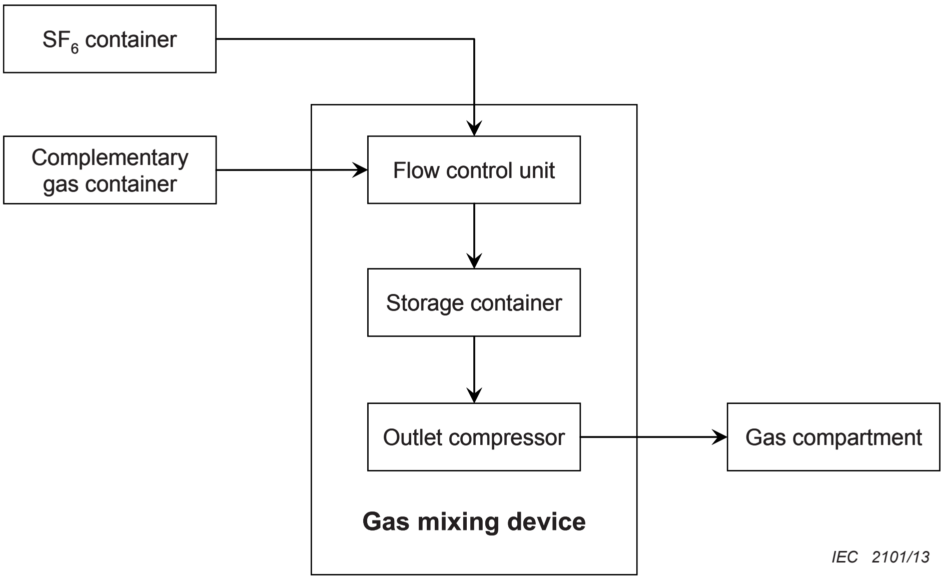


Figure D.2 – Gas mixing device

The flow of both $SF_6$ and the complementary gas is controlled by the flow control unit so that the storage container is filled with the preselected mixture. The outlet pressure (i.e. the filling pressure in the gas compartment) is controlled by the outlet compressor.

Desirable characteristics are:

- adjustable $SF_6$ percentage and outlet pressure (i.e. filling pressure);
- gas mixing ratio (i.e. $SF_6$ percentage): 10 % to 80 % by vol.;
- maximum outlet pressure: up to 1,0 MPa;
- $SF_6$ inlet in liquid state;
- possibility of mixing little as well as large quantities of gas.

# Annex E
(informative)

# Sulphur hexafluoride

## E.1 General

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 high-voltage transmission and distribution of electricity (e.g. 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, tyres, high performance radar, tracer gas for meteorological measurements and in power plant piping, and military applications.

## E.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 $N_2$, up to temperatures of about 180 °C.

Table E.1 lists the main chemical characteristics.

**Table E.1 – Main chemical characteristics of $SF_6$ [16]**

| | |
|---|---|
| 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 |

NOTE The CAS Number is assigned by the Chemical Abstracts Service who maintain a registry of chemical substance information. It has no chemical significance. Access to the information is via a subscription service.

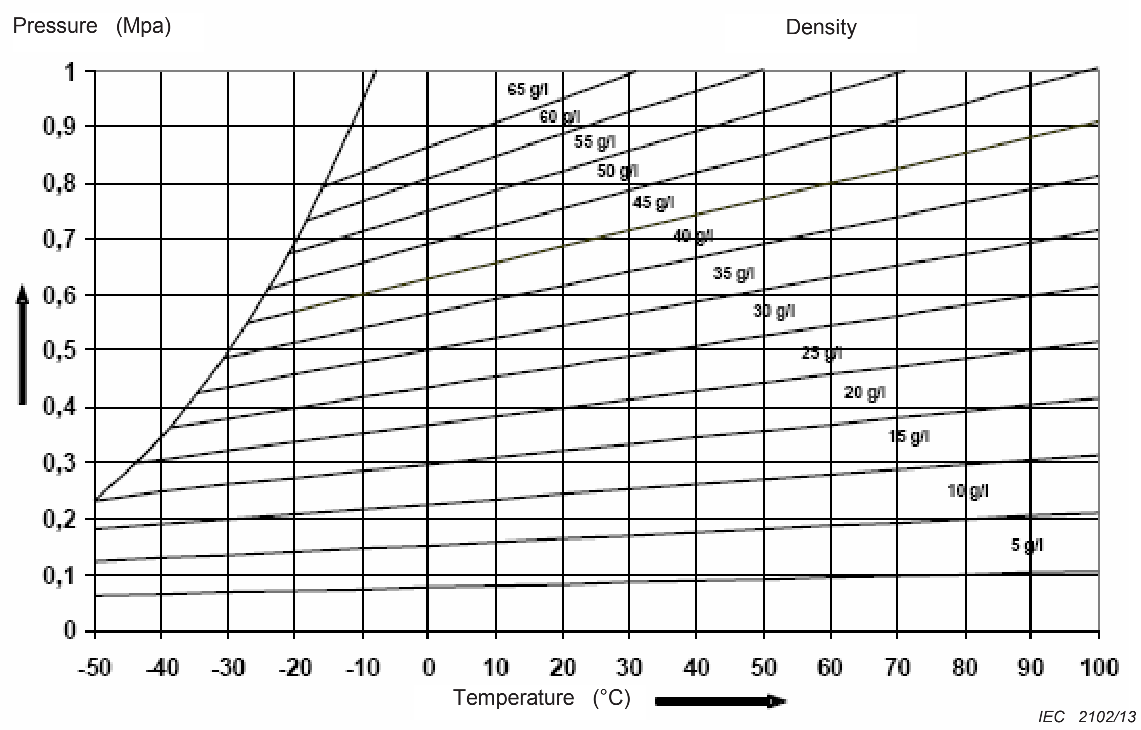
## E.3 Physical properties

$SF_6$ 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 1,0 MPa absolute. The pressure/temperature/density characteristics of the gas are shown in Figure E.1.



IEC 2102/13

Figure E.1 – Pressure/temperature/density characteristics for $SF_6$ [16]

Table E.2 lists the main physical characteristics.

**Table E.2 – Main physical characteristics of $SF_6$ [16]**

| | |
|---|---|
| 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 | 1,000 783 |
| Heat of formation | -1 221,58 ± 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 E.1 |

## E.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 E.3 lists the main electrical characteristics of $SF_6$.

**Table E.3 – Main electrical characteristics of $SF_6$ [16]**

| | |
|---|---|
| Critical breakdown field relative to pressure | 89 V/(m×Pa) |
| Relative dielectrical constant at 25 °C and 0,1 MPa absolute | 1,002 04 |
| Loss factor (tan $\delta$) at 25 °C and 0,1 MPa absolute | $<2,0\times10^{-7}$ |
| Effective ionisation coefficient | $\frac{\alpha}{p} = \mathrm{A}\frac{E}{p} - \mathrm{B}$<br>$\alpha$: $m^{-1}$<br>$E$: V/m<br>$p$: Pa<br>A: $2,8\times10^{-2}$/V<br>B: 89 V/(m×Pa) |

## E.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 (e.g. 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. Chambers containing $SF_6$ should not be entered without adequate ventilation and personal protection equipment.

$SF_6$ 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 μl/l (1 000 ppmv or 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 [17]. 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 F.

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 F
(informative)

# Environmental effects of $SF_6$

## F.1 General

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.

## F.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.

## F.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 [16] because they do not contain either chlorine or bromine.

## F.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 °C (from –18 °C to the actual 15 °C) [18].

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 [20] 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 Fourth Assessment Report (AR4) in Autumn 2007 [18].

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 compared using the Life Cycle Assessment – LCA approach as regulated by ISO 14040 [2].

The Electric Industry utilises $SF_6$ in a closed cycle, banking it e.g. 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 that of 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 [21], Asia [22], and North America [23] and [24]. 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.

## F.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 G 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.

## F.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 [25] 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.

Certain countries have recently introduced recording and reporting of $SF_6$ emissions in their legislation.

# Annex G
(informative)

# $SF_6$ by-products

## G.1 Decomposition of $SF_6$

### G.1.1 General

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 [12], and [16]. 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:

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

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 $SF_6$.

### G.1.2 The 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 reaction (G.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:

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

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

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

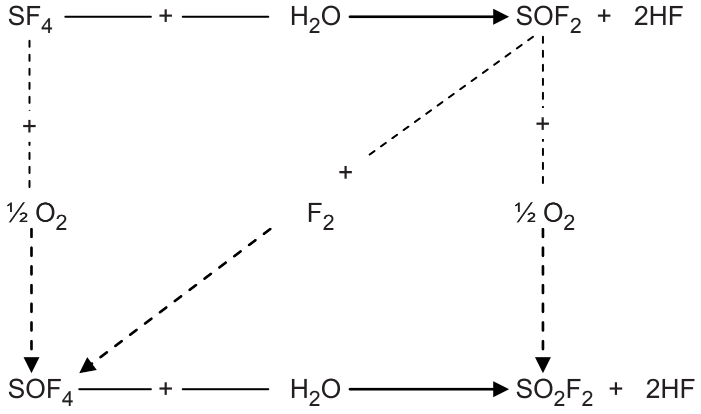
$$SF_5 + O \xrightarrow{\hspace{6em}} SOF_4 + F \qquad \text{(G.5)}$$

The oxygen involved in the reactions (G.2), (G.3), (G.4), and (G.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:

$$F + H_2O \xrightarrow{\hspace{6em}} HF + OH \qquad \text{(G.6)}$$

$$SF_5 + OH \xrightarrow{\hspace{6em}} SOF_4 + HF \qquad \text{(G.7)}$$



(G.8)

The dashed lines in reaction (G.8) indicate reactions that occur only to a limited degree during $SF_6$ decomposition in an arc. Whilst the reactions of (G.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 (G.2), (G.3) and (G.4). It is also possible that HF formed by the reactions of (G.8) further reacts with metal vapours to produce metal fluorides.

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

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

$$SOF_2 + H_2O \xrightarrow{\hspace{6em}} SO_2 + 2HF \qquad \text{(G.9)}$$

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 [26].

### G.1.3 $SF_6$ 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 (G.8) will predominate [26].

### G.1.4 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 [16].

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.

## G.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.

## G.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 [16].

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.

## G.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 [12].

# Annex H
(informative)

# Procedure for evaluating the potential effects on health of $SF_6$ by-products

## H.1 General

This annex suggests procedures for the evaluation of the risks to health due to $SF_6$ released into the local atmosphere by leakage and in the event of an internal arc fault.

During normal service $SF_6$ remains inside the electric power equipment and the gaseous 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, e.g. internal arc fault. It is necessary to differentiate clearly between leakage conditions and internal arc fault situations leading to a sudden release of $SF_6$, when evaluating health risk.

In case of leakage it is necessary to consider the effects of long-term exposure to the gaseous by-products of $SF_6$. The concentrations of these by-products in the air should remain low enough to present no threat to unprotected personnel during a normal working period of e.g. 8 h.

In case of a sudden release of $SF_6$ due to an internal arc fault, the emergency procedure required by the local regulation may imply a momentary exposure. By-product concentrations of higher levels than would be tolerable during e.g. 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 emissions and this requires detailed knowledge of all of the by-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 $SF_6$.

The following clauses give the procedures for calculating the risks associated with the presence of $SF_6$ by-products in the atmosphere due to leakage and to internal arc fault together with the principles adopted for performing those calculations.

## H.2 Formation and health effects of $SF_6$ by-products

### H.2.1 Formation of $SF_6$ 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 G.1.2. 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: S, F, H, N, O and diverse ions. The heating of the electrodes and the insulating parts by the arc adds vapours of Cu, W, C and Al 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 G. The quantities formed are directly related to the power injected into the gas volume.

In case of power arcing, the most frequently encountered by-products are: $SOF_2$, $SO_2$, HF and also $CF_4$, $SF_4$ and $SO_2F_2$ [27]. In case of low energy electrical discharges, $S_2F_{10}$ is also formed in extremely small quantities [28], [29] and [30].

### H.2.2 Effects of $SF_6$ by-products on health

#### H.2.2.1 General

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 into account the concentration of each by-product in relation to the permissible concentrations for the appropriate exposure time. Equation (H.1) should be adopted to calculate the total risk associated to the by-products.

$$\text{Risk}_{\text{tot}} = \sum_i \frac{\text{Concentration}\left(\text{by - product}\right)_i}{\text{Threshold}\left(\text{by - product}\right)_i} \leq 1 \tag{H.1}$$

#### H.2.2.2 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 separately treated;
- 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 should be estimated by studying the concentration of this component alone.

A survey of the majority of the work carried out over the past decades on high power arc decomposition of $SF_6$ [27], [31] concludes that the total health risk to personnel, due to arc decomposed $SF_6$, is predominantly dependent on the $SOF_2$ concentrations generated.

Hydrolysis of $SOF_2$ may occur in the presence of significant concentrations of moisture, producing $SO_2$ and HF, as reported in G.1.2. For the time being, no OEL (Occupational Exposure Limit) has been defined for $SOF_2$. For this reason, it is assumed that hydrolysis always takes place giving HF and $SO_2$. The potential effect on health is then evaluated on those gaseous by-products (see Table H.1).

#### H.2.2.3 Exposure duration and dilution in air

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

- concentration within the surrounding volume;
- time duration of exposure, leading to the selection of the appropriate exposure limit.

When a leakage situation is calculated, the OEL (Occupational Exposure Limit) concentration, defined as TWA (Time Weighted Average over an 8 h per day, 40 h per week exposure limit), should be used.

Under abnormal conditions e.g. internal arc fault, personnel immediately leave the room of the electric power equipment and the exposure is hence momentary. Under those conditions, concentrations defined as C (Ceiling exposure limit, values never to be exceeded), should be employed. When the C value is not defined, the STEL (Short Term Exposure Limit) could be adopted. The STEL refers to an average exposure of 15 min that should not be exceeded during the 8 hours working time.

The occupational exposure limits (OELs) defined by the American Conference of Governmental Industrial Hygienists (ACGIH) [33] for $SO_2$, HF, and $S_2F_{10}$ are given in Table H.1.

Table H.1 – OELs for $SO_2$, HF, and $S_2F_{10}$

| OEL | $SO_2$ | HF | $S_2F_{10}$ |
|---|---|---|---|
| TWA (µl/l) | 2 | 0,5 | Not defined |
| STEL (µl/l) | 5 | Not defined | Not defined |
| C (µl/l) | Not defined | 2 | 0,01 |
| NOTE So far, no OEL has been defined for $SOF_2$. | | | |

### H.2.3 Quantitative estimation of gaseous by-products

#### H.2.3.1 General

The quantity of gaseous by-products formed during an electrical discharge is generally referred to the energy in joule dissipated in the gas. This is called as production rate, $r$.

Experimental results are generally quoted in mol/J but another unit widely adopted is l/kJ. The conversion is based on the fact that 1 mol of ideal gas occupies 24,37 l, at 20 °C and at 100 kPa, and is given in Equation (H.2).

$$1 \text{ mol/J} = 24{,}37 \times 10^3 \text{ l/kJ} \qquad \text{(H.2)}$$

The estimation of the production rates of $SOF_2$ due to arcing and $S_2F_{10}$ due to low energy discharge, both sparking and partial discharges in the gas, is given in H.2.3.2, H.2.3.3, and H.2.3.4, respectively.

#### H.2.3.2 Estimation of the $SOF_2$ production rates due to arcing

The $SOF_2$ production rate is experimentally determined and depends on the electrode material used and the type of discharge considered. Exothermic reactions, which occur with aluminium electrodes, seem to enhance the production rate.

The values used here have been averaged over the range of presently available data found in the literature [27] and [31].

Table H.2 – $SOF_2$ production rate

| Electrode material | $SOF_2$ production rate ($r$) | |
|---|---|---|
| | mol/J | l/kJ |
| Cu, Fe, WCu | $150 \times 10^{-9}$ | $3{,}7 \times 10^{-3}$ |
| Al | $600 \times 10^{-9}$ | $15 \times 10^{-3}$ |
| NOTE Aluminium electrodes are assumed only for GIS bus-bar situations. | | |

#### H.2.3.3 Estimation of the $S_2F_{10}$ production rate due to sparking

Manoeuvring disconnectors produces sparking, which is considered as a low energy discharge. Average parameters are: 1 kV arc voltage drop, 0,25 A capacitive current and 1 s time duration, resulting in 0,25 kJ per each sparking event. However, individual sparks may reach up to 3 kA peak current for only a few tens of microseconds.

In the absence of published data, the production rate of $0{,}05 \times 10^{-9}$ mol/J (or $1{,}22 \times 10^{-6}$ l/kJ) is chosen for $S_2F_{10}$ due to sparking, which reflects a situation at the lower end of the spark discharge range but more than 2 000 times greater than for arcs. This has been confirmed as being realistic by measurements on a real disconnector under highly accelerated operation conditions [29].

#### H.2.3.4 Estimation of the $S_2F_{10}$ production rate due to partial discharges

Single components of high-voltage switchgear and controlgear or sub-assemblies in which they are contained shall not exceed the maximum permissible partial discharge level of $q$ = 5 pC (see 6.2.9.102 of IEC 62271-203:2011).

At rated voltage $U_r$, the energy dissipated during each single partial discharge event is therefore:

$$E = q \times \frac{U_r}{\sqrt{3}} \tag{H.3}$$

which always falls into the micro to nanojoule energy range.

The $S_2F_{10}$ production rate due to partial discharges at power frequency is not available in the literature. A value of $0,2 \times 10^{-9}$ mol/J (or $4,88 \times 10^{-6}$ l/kJ) is obtained by extrapolating the experimental results for sparking in the very low energy region.

### H.2.4 Procedures for health risk evaluation

The procedures for the evaluation of the potential effects on health of gaseous by-products are based on the following assumptions:

- the equipment room is completely closed and ventilation is inoperative during the period of interest;
- the adsorbers fitted into the electric power equipment do not reduce the amount of gaseous by-products during the period of interest;
- the gas emitted uniformly mixes with the air in the room containing the electric power equipment in a short time with respect to the working day or exposure duration.

Figure H.1 describes the typical procedure to follow for the evaluation of the potential effects on health of the by-products formed during arcing (either power interruption or capacitive switching) in $SF_6$. It is applicable to both leakage and internal arc fault cases.

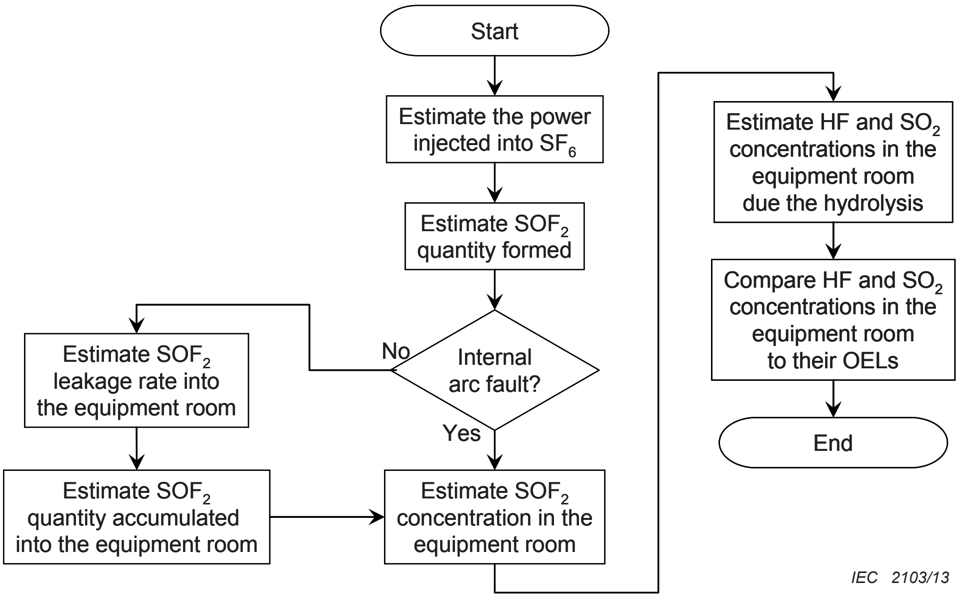


**Figure H.1 – Procedure for the evaluation of the potential effects on health due to arcing**

The power injected during one single event into the electric power equipment should be evaluated. Depending on the circumstances, e.g. power arcing, capacitive arcing, corona discharge, this could be thought as arc voltage drop times arc current times arc duration or as voltage drop times charge transferred. The cumulated power is then evaluated multiplying the power of the single event by the number of events taking place during the reference period.

The quantity of $SOF_2$ formed within the electric power equipment is the power itself times the $SOF_2$ production rate. The $SOF_2$ production rate is a non-linear function of the power, the quantity of $SF_6$, the time duration and the electrode material. Numerical values are determined by experiments (see H.2.3.2).

In case of internal arc fault, the bursting disk bursts and the whole $SOF_2$ quantity is suddenly released into the switchgear room, which is the worst case scenario.

In case of leakage, only a small portion of the $SOF_2$ quantity formed into the electric power equipment transfers to the switchgear room and accumulates over a certain period of time. Under this condition, if $V_{\text{SOF2,équipment}}$ is the $SOF_2$ quantity formed inside the electric power equipment in litres and $F_{\text{p,rel}}$ is the leakage rate of the electric power equipment in % p.a., the $SOF_2$ quantity accumulated into the switchgear room during one day is:

$$V_{\text{SOF2,room}} = \frac{V_{\text{SOF2,equipment}} \times F_{\text{p,rel}}}{100 \times 365} \tag{H.4}$$

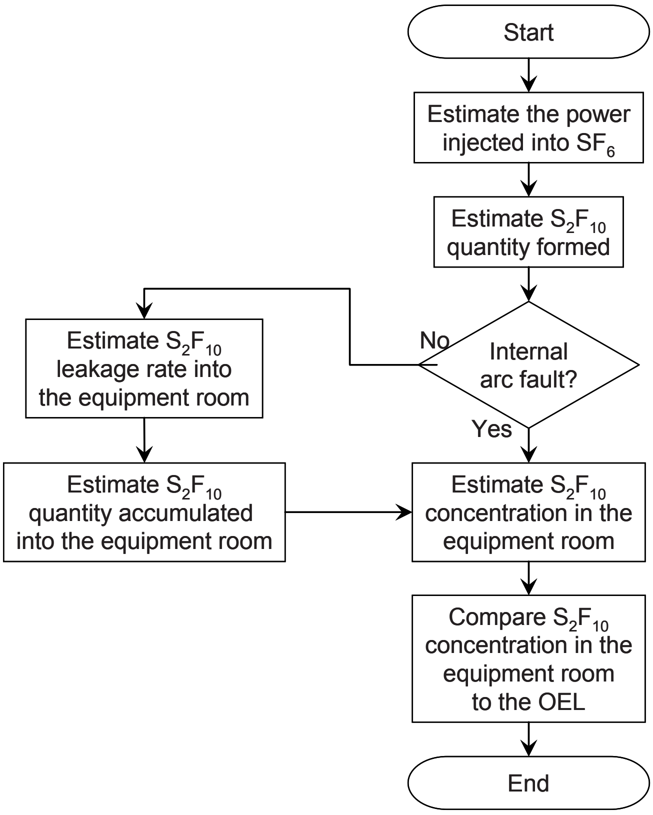
The $SOF_2$ concentration in the equipment room is the $SOF_2$ quantity into the equipment room divided by the volume of the switchgear room. For outdoor installations, the same evaluation should be performed considering the volume of a virtual equipment room.

Due to hydrolysis in the equipment room, the HF concentration in μl/l is twice the $SOF_2$ concentration in μl/l and the $SO_2$ concentration in μl/l is equal to the $SOF_2$ concentration in μl/l.

The potential effect on health of the by-products is then evaluated comparing the HF and the $SO_2$ concentrations in the equipment room to the OELs (Occupational Exposure Limits). The total risk $R_{\text{tot}}$ should be defined as:

$$R_{\mathrm{tot}} = \frac{\mathrm{Concentration(SO_2)}}{\mathrm{TLV\ (SO_2)}} + \frac{\mathrm{Concentration(HF\ )}}{\mathrm{TLV\ (HF)}} \leq 1 \qquad \text{(H.5)}$$

A similar procedure can be adopted for the evaluation of the potential effects on health of $S_2F_{10}$ due to low energy electrical discharges. In this case, no hydrolysis takes place. The procedure is described in Figure H.2.



*IEC 2104/13*

**Figure H.2 – Procedure for the evaluation of the potential effects on health due to low energy discharges**

## H.3 Conclusions

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 by-products, formed by arcing and by low-energy discharges, released due to leakage from $SF_6$-filled electric power equipment, reach negligible concentrations in the workplace atmosphere. Therefore there is no cause for concern and no need for precautions other than the normal ventilation practices for low-lying areas. This is still valid even in the case of abnormal leakage situations (a leakage rate for example 2 orders of magnitude higher than the normal rate).

However, 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. In any situation of this sort, basic safety procedures include evacuation rules are designed to ensure that personnel are exposed to exhausted materials for a time as short as possible. Furthermore, forced ventilation and/or venting ensure the concentration levels can be reduced within minutes.

For outdoor installations 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.

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

# Annex I
(informative)

# Cryogenic reclaim of $SF_6$

## I.1 General

This annex describes as example a method used in Australia during the past 15 years to reclaim $SF_6$ based on a cryogenic technique [35], [36], and [37].

## I.2 Applications

The principal use of the cryogenic process is to remove contaminants from used $SF_6$ stored in cylinders returned to the main process plant from a site where it has been removed from electric power equipment.

The process can be used to:

- aggregate the remainder of $SF_6$ from containers that have been used to fill electric power equipment;
- recover $SF_6$ from electric power equipment to a pressure of below 100 Pa without the need for a recovery compressor;
- restore used $SF_6$, even heavily arced or contaminated by air to the standard of technical grade $SF_6$;
- separate $SF_6$ from a mixture of $SF_6$ and nitrogen ($N_2$). All the $SF_6$ can be recovered and essentially none is released to the atmosphere;
- obtain $CF_4$ from an $SF_6$ / $CF_4$ mixture.

## I.3 Physical Background

The process relies on the variation of the saturated vapour pressure of $SF_6$ and its typical contaminants with temperature (see Figure I.1).

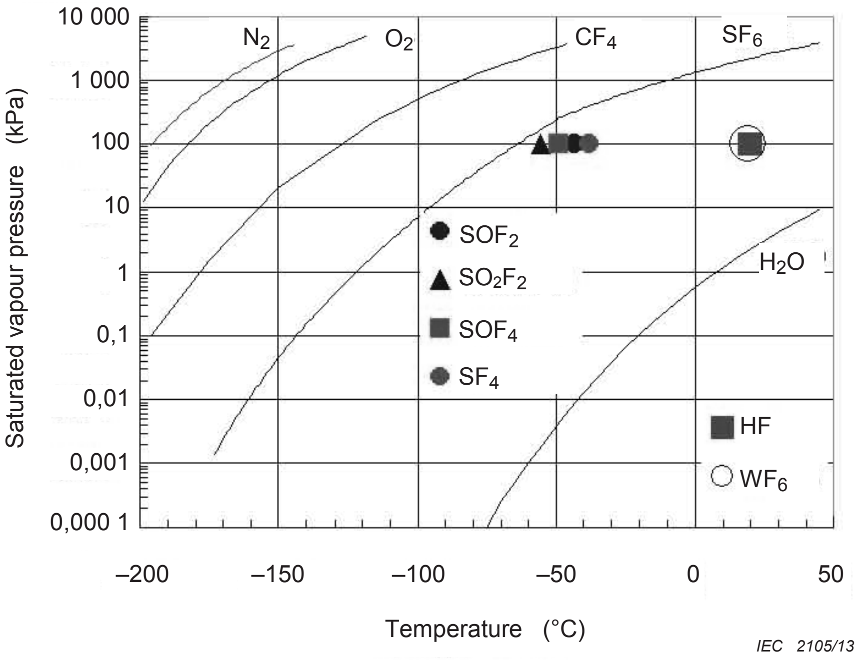


**Figure I.1 – Saturated vapour pressure of various gases as a function of temperature**

## I.4 Cryogenic processes

$SF_6$ is recovered by means of evacuating and cooling a cylinder called capture cylinder. The pressure differential between the cylinder and the gas-filled compartment or the container containing the $SF_6$ to be processed causes the $SF_6$ to be transferred into the cylinder where it will liquefy or solidify due to the low temperatures achieved by liquid nitrogen thereby maintaining a pressure differential until recovery is completed.

The collection process is scalable. A number of cylinders can be connected in parallel to increase collection capacity. Smaller cylinders can be used if the masses of $SF_6$ involved are small. The speed of mass transfer is mainly limited by the diameter of the connecting pipes and with appropriate sized piping the practical limit given by the speed of sound can be attained.

This process can also be used to separate air from $SF_6$ as – provided $SF_6$ is cooled sufficiently – $SF_6$ will freeze inside the capture cylinder allowing the air to be released or evacuated by a conventional vacuum pump.

The process comprises a second step, where a second cylinder called collection cylinder is cooled by liquid nitrogen and connected to the capture cylinder which is allowed to warm up. The pressure differential between the cylinders causes $SF_6$ to be transferred into the collection cylinder while the contaminants remain frozen in the capture cylinder. During the $SF_6$ transfer, the capture cylinder warms up from approx. –150 °C to approx. –45 °C and the pressure in the capture cylinder can be obtained by closing the valve controlling the $SF_6$ transfer and reading the pressure gauge on top of the capture cylinder. This pressure (see Figure I.1) is representative of the highest temperature portion of $SF_6$ in the capture cylinder, even though temperature gradients may be present.

The upper temperature limit in the capture cylinder (i.e. approx. –45 °C) is set to limit the concentration (dew point) of moisture transferred to the collection cylinder. This upper temperature limit must also be low enough to also prevent transfer of reactive gaseous by-products that may be present in the capture cylinder.

The capture cylinder may be partly immersed in a refrigerated bath to allow for a better temperature control.

## I.5 Description of a cryogenic reclaimer [36]

A cryogenic reclaimer comprises the following components:

- gas cylinders (see D.2.6 in addition suitable for cryogenic temperatures);
- insulated dewars meeting local safety requirements and capable of withstanding –220 °C;
- vacuum pump (see D.2.4);
- optional filter, used for reclaim heavily arced gas (see D.2.3);
- sampling point (see 4.2.3 and D.7);
- valves, fittings, pressure gauges and gas piping (see D.2.8, D.2.9, D.2.10, and D.3, in addition suitable for cryogenic temperatures where relevant);
- liquid nitrogen purchased as needed.

The components can be put together in different configurations according to the task at hand.

Figure I.2 is the flow chart of a cryogenic reclaimer suitable for $SF_6$ recovery on site.

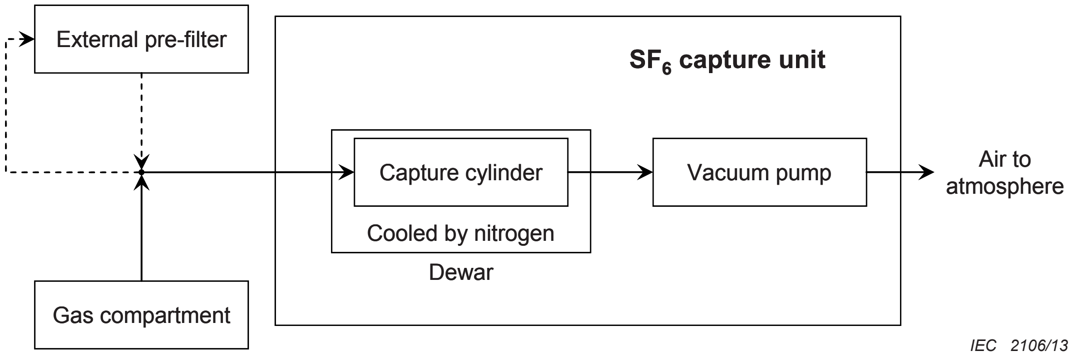


Figure I.2 – Typical cryogenic reclaimer for $SF_6$ recovery on site

The procedure for operation of the manual process is as follows:

- the whole reclaimer is evacuated with the vacuum pump;
- the capture cylinder is chilled with liquid nitrogen and the vacuum in the cylinder itself is maintained by the freezing of $SF_6$ which is continuously drawn in;
- the impure gas entering the process can be directed through a filter if it contains a significant amount of solid contaminants as in the case of heavily arced gas;
- once the gas capture capacity has been reached, the upstream valves are closed and the downstream valves opened;
- the vacuum pump can be used to evacuate and draw off all the gaseous components above the frozen $SF_6$ i.e. oxygen and nitrogen;
- the downstream valves are closed and the cylinder can be removed, warmed up and transported.

Figure I.3 is the flow chart of a cryogenic reclaimer suitable for removing contaminants.

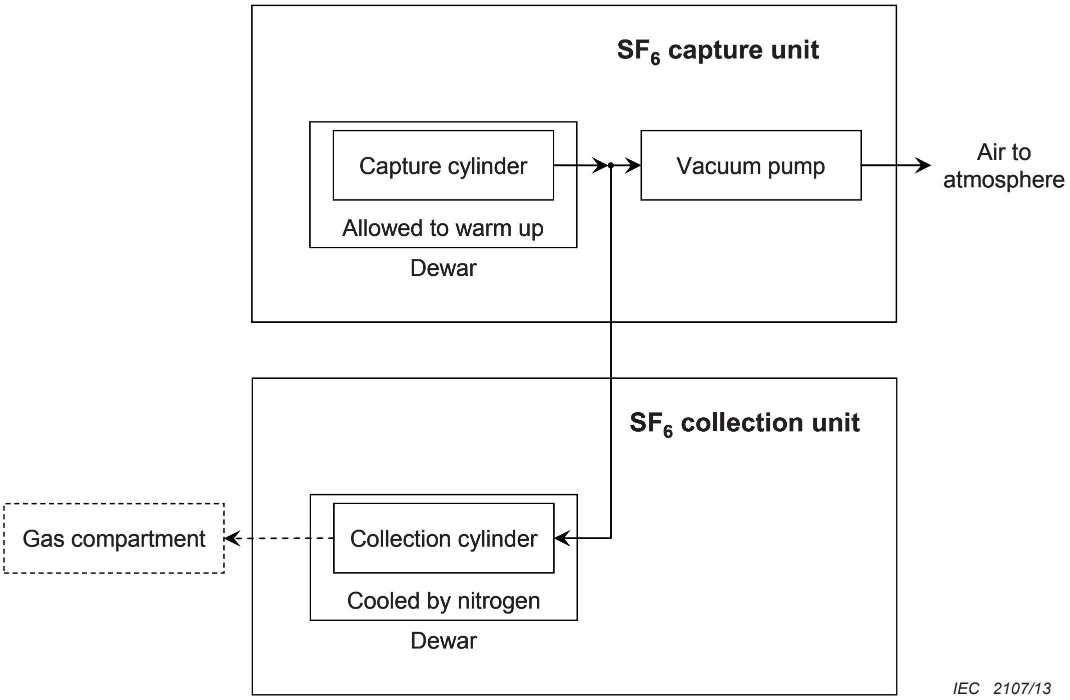


**Figure I.3 – Typical cryogenic reclaimer for removing contaminants**

The procedure for operation of the manual process is as follows:

- the capture cylinder and the collection cylinder are chilled with liquid nitrogen;
- the vacuum pump can be used to evacuate and draw off all the gaseous components above the frozen $SF_6$ i.e. oxygen and nitrogen;
- the capture cylinder is then allowed to warm up to the selected upper temperature limit (e.g. –45 °C);
- pure $SF_6$ is transferred into the collection cylinder as a consequence of the temperature difference.

The capture cylinder is likely to end up containing solid contaminants from heavily arced $SF_6$ and requires cleaning after use.

# Annex J
(normative)

# Handling of $SF_6$ mixtures

## J.1 General

$SF_6$ mixtures are used in electric power equipment mainly for cold ambient applications, typically under –40 °C. Other applications at normal ambient temperature include gas insulated transmission lines and gas insulated transformers. $SF_6$ is mixed with a complementary gas, typically $N_2$ or $CF_4$, in the percentage as specified by the Original Equipment Manufacturer in the operating instruction manual, typically from 10 % to 75 % volume.

The scope of this annex is to address the particularities for handling $SF_6$ mixtures during installation, commissioning, service life and disposal at the end-of-life of electric power equipment.

## J.2 Filling gas compartments with $SF_6$ mixtures

Clause 3.2 of the present International Standard applies with the exception of step 7 in Table 1 which is replaced by:

- Connect the $SF_6$ container and fill the gas compartment until the rated $SF_6$ partial filling pressure/density is reached. Use a safety valve and a calibrated gauge to avoid overfilling [NOTES 1 and 2].
- Top-up the gas compartment to the rated filling pressure/density (see 3.3) with the complementary gas [NOTE 3].

NOTE 1 Unless otherwise specified by the Original Equipment Manufacturer in the Operating Instruction Manual, the vacuum duration can be prolonged in order to better remove moisture when for example the ambient temperature is freezing.

NOTE 2 $SF_6$ to be introduced into the gas compartment can be either technical grade $SF_6$ or used $SF_6$ suitable for reuse on site.

NOTE 3 Specifications for the complementary gas are given by the Original Equipment Manufacturer in the operating instruction manual.

Alternatively, gas mixing devices (see D.8) or premixed gases may be used to speed-up the process and reduce the probability of accidental mistakes.

NOTE 4 Premixed gases can be obtained from gas suppliers.

## J.3 Re-filling gas compartments with $SF_6$ mixtures to the rated filling pressure/density

Clause 4.1 of the present International Standard applies with the exception of step 3 in

Table 3 which is replaced by:

- Evaluate the intermediate pressure/density $p_\mathrm{i}$ as

$$p_\mathrm{i} = x \times p_\mathrm{rm} + (1 - y) \times p_\mathrm{a} \qquad \text{(J.1)}$$

  where

  – $x$ is the nominal $SF_6$ percentage of the $SF_6$ mixture;

  – $p_\mathrm{rm}$ is the rated filling pressure of the $SF_6$ mixture;

  – $y$ is the actual or measured $SF_6$ percentage of the $SF_6$ mixture in the gas-filled compartment (see 4.2.2);

  – $p_\mathrm{a}$ is the actual or measured pressure of the $SF_6$ mixture in the gas-filled compartment [NOTE 1];

- Connect the $SF_6$ container and fill the compartment until the intermediate pressure/density $p_\mathrm{i}$ is reached. Use a safety valve and a calibrated gauge to avoid overfilling [NOTE 2].
- Top-up the compartment to the rated filling pressure/density $p_\mathrm{rm}$ (see 3.3) with the complementary gas [NOTE 4].

NOTE 1 To reduce the probability of mistakes, $p_\mathrm{i}$ is evaluated at the reference temperature of 20 °C. If required, the pressure is then reported at a different ambient temperature. $p_\mathrm{a}$ is the pressure measured at the ambient temperature reported at the reference temperature of 20 °C.

NOTE 2 $SF_6$ to be introduced into the gas compartment can be either technical grade $SF_6$ or used $SF_6$ suitable for reuse on site.

NOTE 3 Specifications for the complementary gas are given by the Original Equipment Manufacturer in the Operating Instruction Manual.

Alternatively, gas mixing devices (see D.8) or premixed gases may be used to speed-up the process and reduce the probability of accidental mistakes.

NOTE 4 Premixed gases can be obtained from gas suppliers.

## J.4 Rectifying the composition of $SF_6$ mixtures

This subclause applies to compartments of pressure systems containing $SF_6$ mixed with a complementary gas in a percentage not complying with the specifications given by the Original Equipment Manufacturer in the Operating Instruction Manual.

Unless otherwise specified by the Original Equipment Manufacturer in the operating instruction manual, the following steps for rectifying the composition of the $SF_6$ mixture applies:

- Evaluate the recovery pressure/density $p_\mathrm{rec}$ as

  for $y < x$

$$p_\mathrm{rec} = P_\mathrm{r} \times \frac{1 - x}{1 - y} \qquad \text{(J.2)}$$

  for $y > x$

$$p_\mathrm{rec} = P_\mathrm{r} \times \frac{x}{y} \qquad \text{(J.3)}$$

  where:

  – $p_\mathrm{rm}$ is the rated filling pressure of the $SF_6$ mixture;

  – $x$ is the nominal $SF_6$ percentage of the $SF_6$ mixture;

  – $y$ is the actual or measured $SF_6$ percentage of the $SF_6$ mixture in the gas-filled compartment (see 4.2.2);

- recover the $SF_6$ mixture in the gas-filled compartment to the recovery pressure/density $p_\mathrm{rec}$;

- re-fill the gas compartment to the rated filling pressure/density (see J.3).

NOTE To reduce the probability of mistakes, $p_{\mathrm{rec}}$ is evaluated at the reference temperature of 20 °C. If required, the pressure is then reported at a different ambient temperature.

## J.5 Checking the quality of $SF_6$ mixtures

### J.5.1 General

Sublause 4.2 of the present International Standard applies.

NOTE When $SF_6$ is partially liquefied, the actual or measured $SF_6$ percentage can differ from the nominal $SF_6$ percentage of the $SF_6$ mixture. Clause J.7 covers the storage of $SF_6$ mixtures to avoid liquefaction.

### J.5.2 Variation of the composition of $SF_6$ mixtures over time

The composition of an $SF_6$ mixture in a gas-filled compartment varies slightly over time due to the combination of the following causes:

- different leakage rates of $SF_6$ and the complementary gas;
- different decomposition rates of $SF_6$ and the complementary gas by arc;
- different quantities of $SF_6$ and the complementary gas trapped in the cavities of the adsorbers;
- many gas handling operations performed on the same gas-filled compartment.

### J.5.3 Tolerance on the composition of $SF_6$ mixtures

The tolerance on the composition of an $SF_6$ mixture should be specified by the Original Equipment Manufacturer in the Operating Instruction Manual taking into account the possible use of “used $SF_6$ suitable for reuse on site” (see 2.15) and the incertitude associated to measurement devices (see D.4), typical gas handling and cold service conditions.

NOTE The incertitude regarding the $SF_6$ percentage associated to typical on-site gas handling is considered to be 6 %. In laboratory conditions, during type testing of switchgear, the incertitude regarding the $SF_6$ percentage is considered to be 1%.

## J.6 Recovery and reclaim of $SF_6$ mixtures

Clause 5 of the present International Standard applies. See J.7 for storage.

## J.7 Storage and transportation of $SF_6$ mixtures

### J.7.1 General

Containers containing $SF_6$ mixtures shall be tagged with an identification label containing the $SF_6$ percentage and the complementary gas.

For storage and transportation of $SF_6$ mixtures Annex A of the present International Standard applies. In case of temporary storage (e.g. during maintenance, repair) the volume of the container should be large enough to assure that the $SF_6$ partial pressure remains below the $SF_6$ vapour pressure at the minimum storage temperature to avoid $SF_6$ liquefaction.

NOTE Heating elements can be applied to storage containers to increase the effective storage temperature and consequently pressure. The volume of the storage container is therefore substantially reduced.

### J.7.2 Maximum storage pressure to avoid liquefaction

The maximum storage pressure for an $SF_6$ mixture $p_{\mathrm{m}}$ can be calculated according to the following equation

$$p_{\mathrm{m}} = \frac{p_{\mathrm{l}}}{x} \tag{J.4}$$

where:

- $p_{\mathrm{l}}$ is the $SF_6$ vapour pressure at the minimum storage temperature (see Figure J.1);
- $x$ is the nominal $SF_6$ percentage of the $SF_6$ mixture.

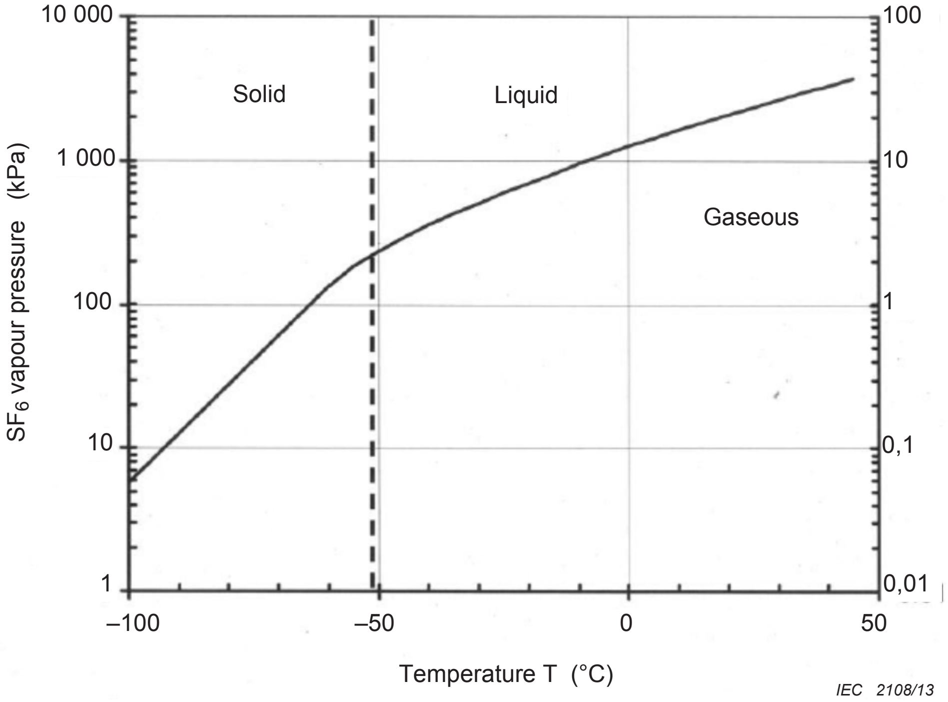


**Figure J.1 – Vapour pressure of $SF_6$**

### J.7.3 Minimum storage volume to avoid liquefaction

The minimum storage volume for the $SF_6$ mixture $v_{\mathrm{m}}$ can be calculated according to the following equation

$$v_{\mathrm{m}} = \frac{m_{\mathrm{SF6}}}{\rho_{\mathrm{l}}} \tag{J.5}$$

where:

- $m_{\mathrm{SF6}}$ is the $SF_6$ quantity to be stored;
- $\rho_{\mathrm{l}}$ is the maximum $SF_6$ density to avoid $SF_6$ liquefaction at the minimum storage temperature (see Figure J.2).

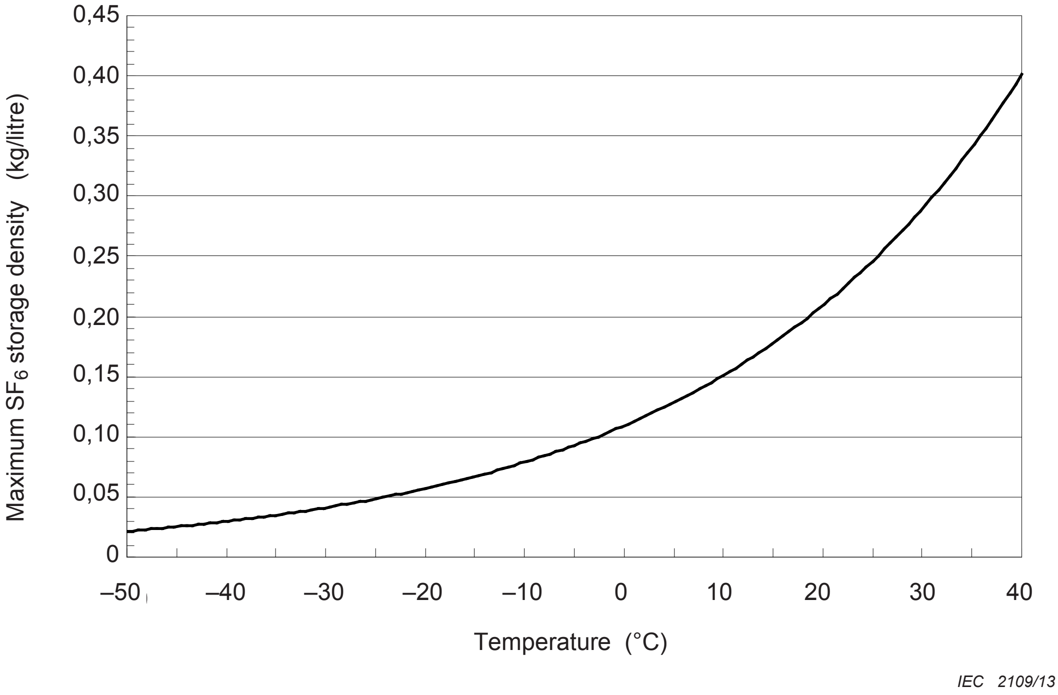


**Figure J.2 – Maximum $SF_6$ storage density to avoid $SF_6$ liquefaction**

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