

INTERNATIONAL STANDARD

NORME INTERNATIONALE



**High-voltage switchgear and controlgear –
Part 4: Handling procedures for sulphur hexafluoride (SF₆) and its mixtures**

**Appareillage à haute tension –
Partie 4: Utilisation et manipulation de l'hexafluorure de soufre (SF₆) et des
mélanges contenant du SF₆**



THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2013 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester.

If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

Droits de reproduction réservés. Sauf indication contraire, aucune partie de cette publication ne peut être reproduite ni utilisée sous quelque forme que ce soit et par aucun procédé, électronique ou mécanique, y compris la photocopie et les microfilms, sans l'accord écrit de la CEI ou du Comité national de la CEI du pays du demandeur.

Si vous avez des questions sur le copyright de la CEI ou si vous désirez obtenir des droits supplémentaires sur cette publication, utilisez les coordonnées ci-après ou contactez le Comité national de la CEI de votre pays de résidence.

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

Useful links:

IEC publications search - www.iec.ch/searchpub

The advanced search enables you to find IEC publications by a variety of criteria (reference number, text, technical committee,...).

It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished

Stay up to date on all new IEC publications. Just Published details all new publications released. Available on-line and also once a month by email.

Electropedia - www.electropedia.org

The world's leading online dictionary of electronic and electrical terms containing more than 30 000 terms and definitions in English and French, with equivalent terms in additional languages. Also known as the International Electrotechnical Vocabulary (IEV) on-line.

Customer Service Centre - webstore.iec.ch/csc

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: csc@iec.ch.

A propos de la CEI

La Commission Electrotechnique Internationale (CEI) est la première organisation mondiale qui élabore et publie des Normes internationales pour tout ce qui a trait à l'électricité, à l'électronique et aux technologies apparentées.

A propos des publications CEI

Le contenu technique des publications de la CEI est constamment revu. Veuillez vous assurer que vous possédez l'édition la plus récente, un corrigendum ou amendement peut avoir été publié.

Liens utiles:

Recherche de publications CEI - www.iec.ch/searchpub

La recherche avancée vous permet de trouver des publications CEI en utilisant différents critères (numéro de référence, texte, comité d'études,...).

Elle donne aussi des informations sur les projets et les publications remplacées ou retirées.

Just Published CEI - webstore.iec.ch/justpublished

Restez informé sur les nouvelles publications de la CEI. Just Published détaille les nouvelles publications parues. Disponible en ligne et aussi une fois par mois par email.

Electropedia - www.electropedia.org

Le premier dictionnaire en ligne au monde de termes électroniques et électriques. Il contient plus de 30 000 termes et définitions en anglais et en français, ainsi que les termes équivalents dans les langues additionnelles. Egalement appelé Vocabulaire Electrotechnique International (VEI) en ligne.

Service Clients - webstore.iec.ch/csc

Si vous désirez nous donner des commentaires sur cette publication ou si vous avez des questions contactez-nous: csc@iec.ch.

INTERNATIONAL STANDARD

NORME INTERNATIONALE



**High-voltage switchgear and controlgear –
Part 4: Handling procedures for sulphur hexafluoride (SF₆) and its mixtures**

**Appareillage à haute tension –
Partie 4: Utilisation et manipulation de l'hexafluorure de soufre (SF₆) et des
mélanges contenant du SF₆**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 29.130.10; 29.130.99

ISBN 978-2-8322-1042-0

**Warning! Make sure that you obtained this publication from an authorized distributor.
Attention! Veuillez vous assurer que vous avez obtenu cette publication via un distributeur agréé.**

CONTENTS

FOREWORD.....	5
INTRODUCTION.....	7
1 General	8
1.1 Scope.....	8
1.2 Normative references	8
2 Terms and definitions	9
3 SF ₆ handling during installation and commissioning	11
3.1 General	11
3.2 Evacuation, filling and checking the SF ₆ quality after filling	11
3.3 Topping-up of SF ₆ pre-filled compartments to the rated filling pressure/density.....	13
3.4 Filling sealed pressure systems.....	15
4 SF ₆ handling during normal service life	15
4.1 Re-filling of SF ₆ to the rated filling pressure/density	15
4.2 Checking the SF ₆ quality.....	16
4.2.1 General	16
4.2.2 Measurement of the SF ₆ quality with portable equipment	16
4.2.3 Sampling and shipment of SF ₆ for off-site analysis.....	17
5 SF ₆ recovery and reclaim during maintenance	18
5.1 General	18
5.2 SF ₆ recovery and reclaim from any compartment of controlled or closed pressure systems containing non-arced or normally arcad SF ₆	18
5.3 Recovery and reclaim from any compartment of controlled or closed pressure systems containing heavily arcad SF ₆	20
6 Dismantling of SF ₆ electric power equipment at the end-of-life	22
6.1 General	22
6.2 End-of-life of controlled or closed pressure systems	23
6.3 End-of-life of sealed pressure systems	23
6.4 SF ₆ recovery and reclaim at the end-of-life of sealed pressure systems	24
6.5 Dismantling of electric power equipment at the end-of-life	26
6.6 By-products at the end-of-life	27
Annex A (informative) Storage and transportation of SF ₆	29
Annex B (informative) Safety and first aid	33
Annex C (informative) Training and certification	39
Annex D (informative) Description of SF ₆ Handling Equipment	43
Annex E (informative) Sulphur hexafluoride	51
Annex F (informative) Environmental effects of SF ₆	55
Annex G (informative) SF ₆ by-products.....	58
Annex H (informative) Procedure for evaluating the potential effects on health of SF ₆ by-products.....	61
Annex I (informative) Cryogenic reclaim of SF ₆	67
Annex J (normative) Handling of SF ₆ mixtures.....	71
Bibliography.....	76

Figure 1 – Evacuation, filling and checking the SF₆ quality after filling.....12

Figure 2 – Topping-up of SF ₆ pre-filled compartments to the rated filling pressure/density	14
Figure 3 – SF ₆ re-filling to the rated filling pressure/density.....	15
Figure 4 – Checking the SF ₆ quality on-site.....	17
Figure 5 – SF ₆ sampling and shipment	18
Figure 6 – Example of recovery and reclaim from any compartment of controlled or closed pressure systems containing non-arced or normally arced SF ₆	19
Figure 7 – Example of recovery and reclaim from any compartment of controlled or closed pressure systems containing heavily arced SF ₆	21
Figure 8 – End-of-life of controlled or closed pressure systems.....	23
Figure 9 – End-of-life of sealed pressure systems.....	24
Figure 10 – SF ₆ recovery and reclaim at the end-of-life of sealed pressure systems.....	25
Figure 11 – Dismantling of electric power equipment	27
Figure D.1 – General purpose reclaimer	43
Figure D.2 – Gas mixing device	49
Figure E.1 – Pressure/temperature/density characteristics for SF ₆ [16]	52
Figure H.1 – Procedure for the evaluation of the potential effects on health due to arcing	65
Figure H.2 – Procedure for the evaluation of the potential effects on health due to low energy discharges	66
Figure I.1 – Saturated vapour pressure of various gases as a function of temperature	68
Figure I.2 – Typical cryogenic reclaimer for SF ₆ recovery on site.....	69
Figure I.3 – Typical cryogenic reclaimer for removing contaminants.....	70
Figure J.1 – Vapour pressure of SF ₆	74
Figure J.2 – Maximum SF ₆ storage density to avoid SF ₆ liquefaction	75
Table 1 – Evacuation, filling and checking the SF ₆ quality after filling.....	13
Table 2 – Topping-up of SF ₆ pre-filled compartments to the rated filling pressure/density.	14
Table 3 – SF ₆ re-filling to the rated filling pressure/density.....	16
Table 4 – Checking the SF ₆ quality on-site	17
Table 5 – SF ₆ sampling and shipment	18
Table 6 – Example of recovery and reclaim from any compartment of controlled or closed pressure systems containing non-arced or normally arced SF ₆	20
Table 7 – Example of recovery and reclaim from any compartment of controlled or closed pressure systems containing heavily arced SF ₆	22
Table 8 – SF ₆ recovery at the end-of-life of sealed pressure systems.....	26
Table 9 – Expected SF ₆ characteristics and quantity of by-products	28
Table A.1 – Methods for storage of SF ₆	29
Table A.2 – Container types and labelling required for storage and transportation of SF ₆	30
Table A.3 – International regulations for shipment of SF ₆	31
Table B.1 – Measures when working with SF ₆ electric power equipment.....	33
Table B.2 – Safety measures when opening or accessing gas compartments.....	34
Table B.3 – Neutralising solutions.....	35
Table B.4 – Additional safety measures	

Table D.1 – Typical filter types used during SF ₆ reclaim	44
Table D.2 – Gas measuring devices	47
Table E.1 – Main chemical characteristics of SF ₆ [16]	51
Table E.2 – Main physical characteristics of SF ₆ [16]	53
Table E.3 – Main electrical characteristics of SF ₆ [16]	53
Table H.1 – OELs for SO ₂ , HF, and S ₂ F ₁₀	63
Table H.2 – SOF ₂ production rate	63

INTERNATIONAL ELECTROTECHNICAL COMMISSION

HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

Part 4: Handling procedures for sulphur hexafluoride (SF₆) and its mixtures

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 62271-4 has been prepared by subcommittee 17A: High-voltage switchgear and controlgear, of IEC technical committee 17: Switchgear and controlgear.

This first edition cancels and replaces the first edition of IEC/TR 62271-303 published in 2008.

This first edition constitutes a technical revision. This edition includes the following significant technical changes with respect to the previous edition:

- a) the description of the potential effects on health of SF₆ by-products (former Annex D of IEC/TR 62271-303:2008) has been replaced by the calculation methods for evaluating of the potential effects on health of SF₆ by-products (see Annex H);
- b) information about cryogenic reclaim of SF₆ have been added (see Annex I);
- c) handling procedures for the most popular SF₆ mixtures have been added (see Annex J).

The text of this standard is based on the following documents:

FDIS	Report on voting
17A/1044/FDIS	17A/1051/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62271, published under the general title *High-voltage switchgear and controlgear*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

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 (SF₆) and its mixtures

1 General

1.1 Scope

This part of IEC 62271 applies to the procedures for handling of SF₆ 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 SF₆ (see Annex B) and to minimize the SF₆ emission to the environment.

This standard generally applies also to gas mixtures containing SF₆. 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 (SF₆) for use in electrical equipment*

IEC 60480, *Guidelines for the checking and treatment of sulphur hexafluoride (SF₆) taken from electrical equipment and specifications for its 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 SF₆

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 SF₆ 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 SF₆ leak is detected, appropriate measures to locate and eliminate it should be arranged.

2.2

handling of SF₆

any process which might involve transfer of SF₆

2.3

evacuation

transfer of a gas different from SF₆ (e.g. air or N₂) which can be released into the atmosphere. The operation is performed utilising a vacuum pump

2.4

recovery of SF₆

transfer of SF₆ 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 SF₆

filling a pre-filled compartment with SF₆ 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 SF₆ 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 SF₆

filling a compartment with SF₆ to the rated filling pressure to assure continuity of service

2.7

reclaim of SF₆

a series of SF₆ handling procedures including recovery and minimum SF₆ 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 SF₆ 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 SF₆ 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 SF₆**

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

2.14**used SF₆**

gas removed from an item of electrical equipment, initially filled with SF₆ 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 SF₆, which occur in both gaseous and solid form.

2.15**used SF₆ suitable for reuse on site**

used SF₆ 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 SF₆ suitable for reuse at the gas manufacturer

used SF₆ 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 SF₆ not suitable for reuse

used SF₆ not falling under the category defined under 2.15 or 2.16

Note 1 to entry: Used SF₆ not suitable for reuse is disposed according to local or international regulations on waste management.

2.18

non-arced SF₆

used SF₆ having less than approximately 1 ml/l (0,1 % by volume) of gaseous by-products

Note 1 to entry: Non-arced SF₆ 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 arc'd SF₆

used SF₆ 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 arc'd SF₆ 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 arc'd SF₆

used SF₆ having more than approximately 10 ml/l (1 % by volume.) of gaseous by-products

Note 1 to entry: Heavily arc'd SF₆ 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

SF₆ mixture

gas mixture formed by SF₆ and a complementary gas, typically N₂ or CF₄

3 SF₆ handling during installation and commissioning

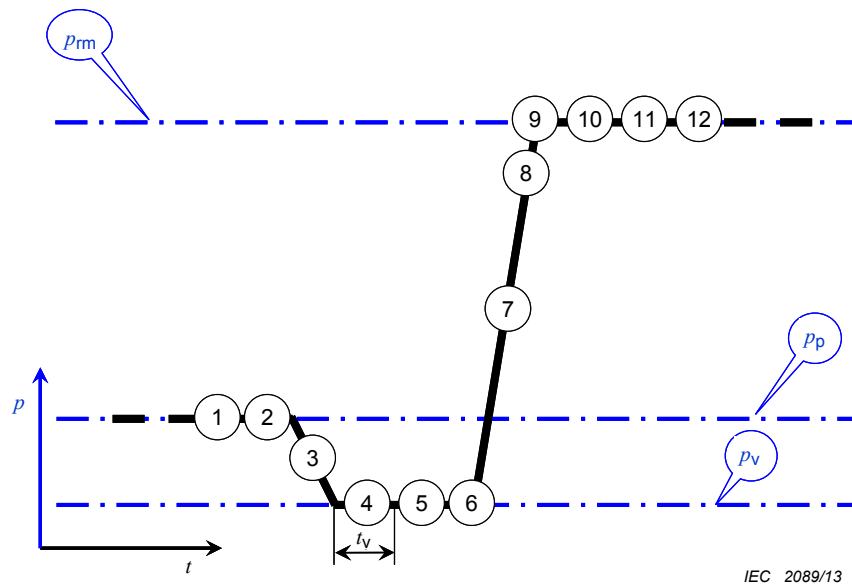
3.1 General

This clause provides guidance for working with technical grade SF₆, according to IEC 60376 or used SF₆ suitable for reuse on site, according to IEC 60480 i.e. when a gas compartment is filled, after the switchgear and controlgear has been installed on site.

3.2 Evacuation, filling and checking the SF₆ quality after filling

This subclause applies to switchgear compartments of pressure systems that currently contain a gas different from SF₆ (typically air or N₂) at ambient pressure or slight overpressure (typically 0,1 MPa to 0,15 MPa).

The following detailed sequence of operations for air/N₂ evacuation and SF₆ 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.



IEC 2089/13

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

Figure 1 – Evacuation, filling and checking the SF₆ quality after filling

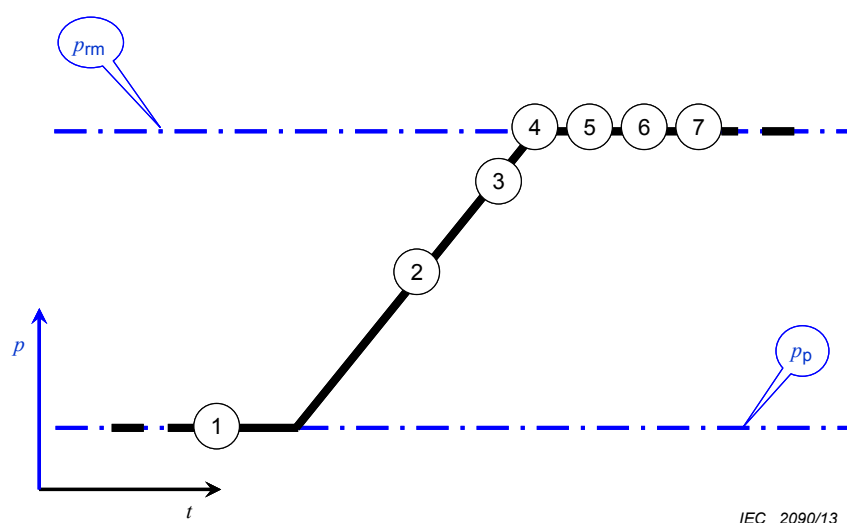
Table 1 – Evacuation, filling and checking the SF₆ quality after filling

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 SF₆ to be introduced into the gas compartment may be either technical grade SF₆ or used SF₆ suitable for reuse on site. ^c No SF₆ 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 SF₆ quality may be checked prior to the filling operation (see 4.2). ^d If the gas compartment has a small volume, re-filling after SF₆ quality checking may be required.		

3.3 Topping-up of SF₆ 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 SF₆ 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 SF₆ 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.



IEC 2090/13

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

Figure 2 – Topping-up of SF₆ pre-filled compartments to the rated filling pressure/density

Table 2 – Topping-up of SF₆ 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 SF₆ in the factory and no further SF₆ 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 SF₆ handling during normal service life

4.1 Re-filling of SF₆ 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 SF₆ 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.

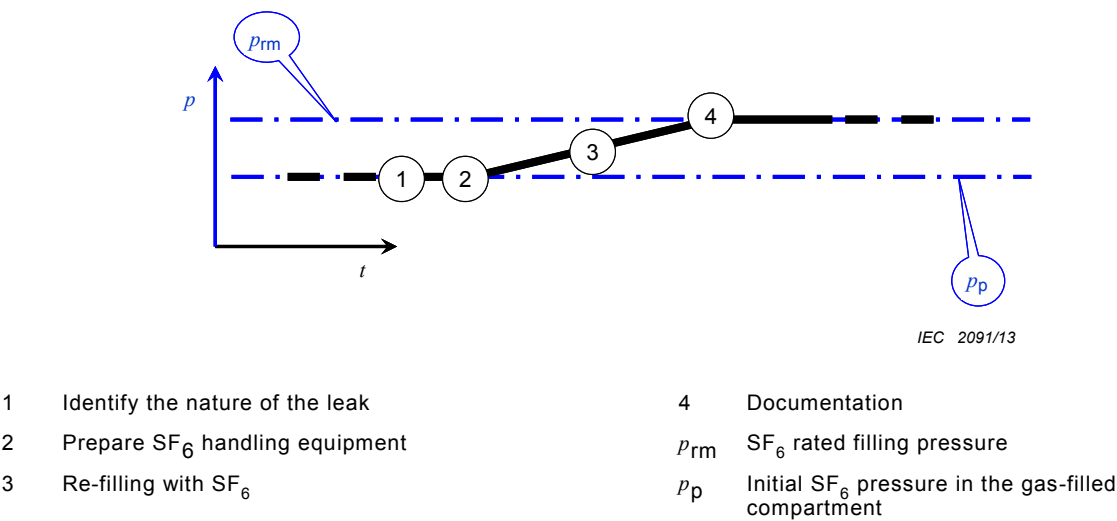


Figure 3 – SF₆ re-filling to the rated filling pressure/density

Table 3 – SF₆ 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 SF₆ quality

4.2.1 General

The measurement of the SF₆ 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 SF₆ quality checks according to IEC 60480 are moisture content (e.g. water content in mg/kg), SF₆ 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.

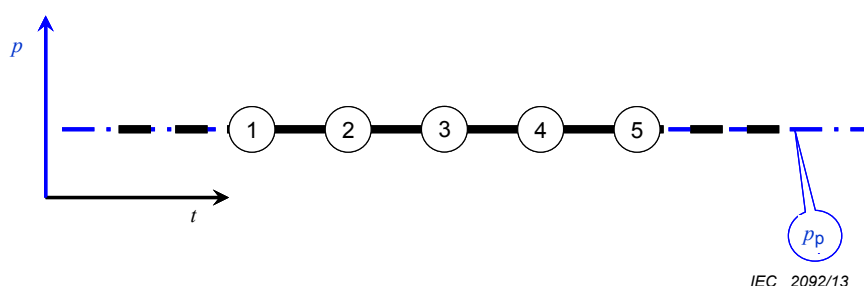
The total reactive gaseous by-products shall be checked first to prevent damage of other portable equipment, if the history of the gas-filled compartment is unknown.

4.2.2 Measurement of the SF₆ quality with portable equipment

This subclause applies to SF₆ filled compartments of controlled and closed pressure systems or SF₆ filled containers to check the quality of the gas with portable equipment.

The following detailed sequence of operations for an on-site SF₆ 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 | 4 | Disconnect the portable equipment |
| 2 | Connect the portable equipment | 5 | Documentation |
| 3 | Read the portable equipment | p_p | SF_6 pressure in the gas-filled compartment |

Figure 4 – Checking the SF_6 quality on-site

Table 4 – Checking the SF_6 quality on-site

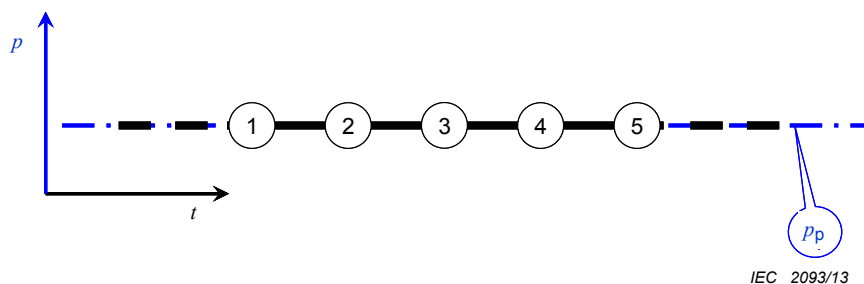
Step		Procedure
1	Prepare portable equipment	Check that the portable equipment is working properly, the ambient conditions are within the working range, e.g. temperature, ^a the gas connections are clean and dry, hoses are evacuated and no leaks on connection fittings exist to avoid any false measurements. 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 – SF₆ sampling and shipment

Table 5 – SF₆ 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 SF₆ recovery and reclaim during maintenance

5.1 General

This clause contains the procedures for SF₆ recovery and reclaim from any gas-filled compartment during maintenance.

Once SF₆ 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 SF₆ recovery and reclaim from any compartment of controlled or closed pressure systems containing non-arced or normally arced SF₆

This subclause applies to any compartment of controlled or closed pressure systems containing non-arced or normally arced SF₆, when it is recovered for maintenance.

The partial SF₆ pressure in the gas compartment prior to flooding with (dry) air and opening shall be lower than 2 kPa.

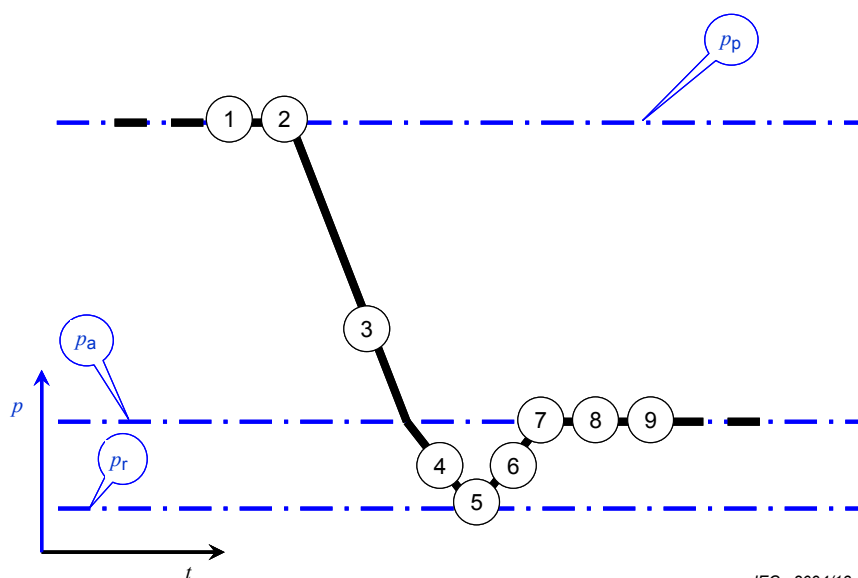
Figure 6 and Table 6 can be adopted as an example of the detailed sequence of operations for SF₆ recovery and reclaim from any compartment of controlled or closed pressure systems containing non-arced or normally arced SF₆, except as otherwise specified in the handling

procedure detailed by the Original Equipment Manufacturer in the Operating Instruction Manual.

There are cases where the SF₆ 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 SF₆ pressure of 2 kPa (e.g. dilution method) in the gas compartment prior to opening.

NOTE The partial SF₆ pressure is the pressure of SF₆ occupying alone the whole volume of the gas compartment. For pure SF₆ if the procedure detailed in Figure 6 and Table 6 is followed, SF₆ is the only gas in the gas compartment and therefore the partial SF₆ pressure is practically equal to the SF₆ residual pressure.

The safety rules given in Annex B should be followed.



IEC 2094/13

- | | | | |
|---|--|-------|--|
| 1 | Prepare SF ₆ handling equipment | 7 | Open the gas compartment |
| 2 | Connect external pre-filters (optional step) | 8 | Remove solid by-products and adsorbers when present |
| 3 | SF ₆ recovery | 9 | Neutralisation, if required |
| 4 | Minimise residual SF ₆ content | p_p | SF ₆ pressure in the gas-filled compartment |
| 5 | Documentation | p_a | Atmospheric pressure |
| 6 | Flood with (dry) air | 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 arcad SF₆

Table 6 – Example of recovery and reclaim from any compartment of controlled or closed pressure systems containing non-arced or normally arced SF₆

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 SF₆

This subclause applies to any compartment of controlled or closed pressure systems containing heavily arced SF₆, when it is recovered for maintenance.

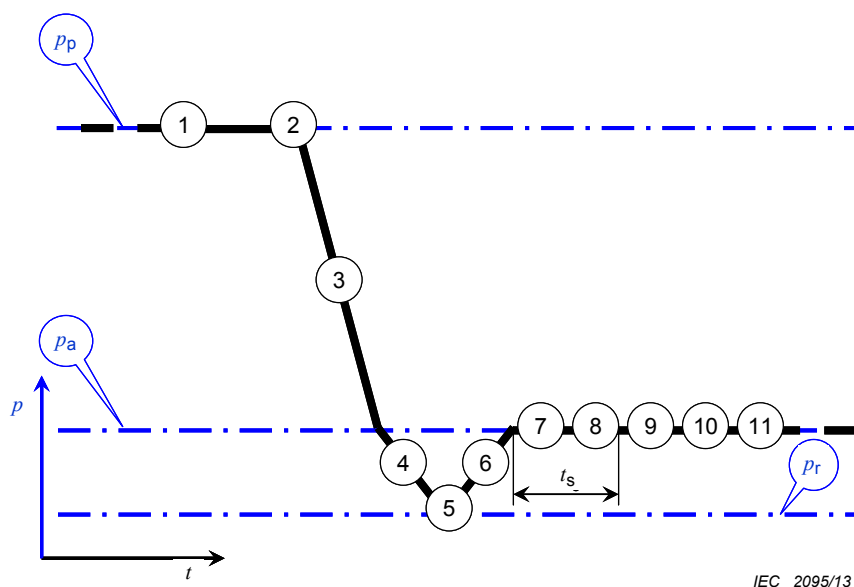
The partial SF₆ pressure in the gas compartment prior to flooding with (dry) air and opening shall be lower than 2 kPa.

Figure 7 and Table 7 can be adopted as an example of the detailed sequence of operations for SF₆ recovery and reclaim from any compartment of controlled or closed pressure systems containing heavily arced SF₆ except as otherwise specified in the handling procedure detailed by the Original Equipment Manufacturer in the Operating Instruction Manual.

There are cases where the SF₆ 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 SF₆ 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.



IEC 2095/13

- | | |
|--|--|
| 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 ≥ 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 SF₆

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 N₂ 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 SF₆ 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.

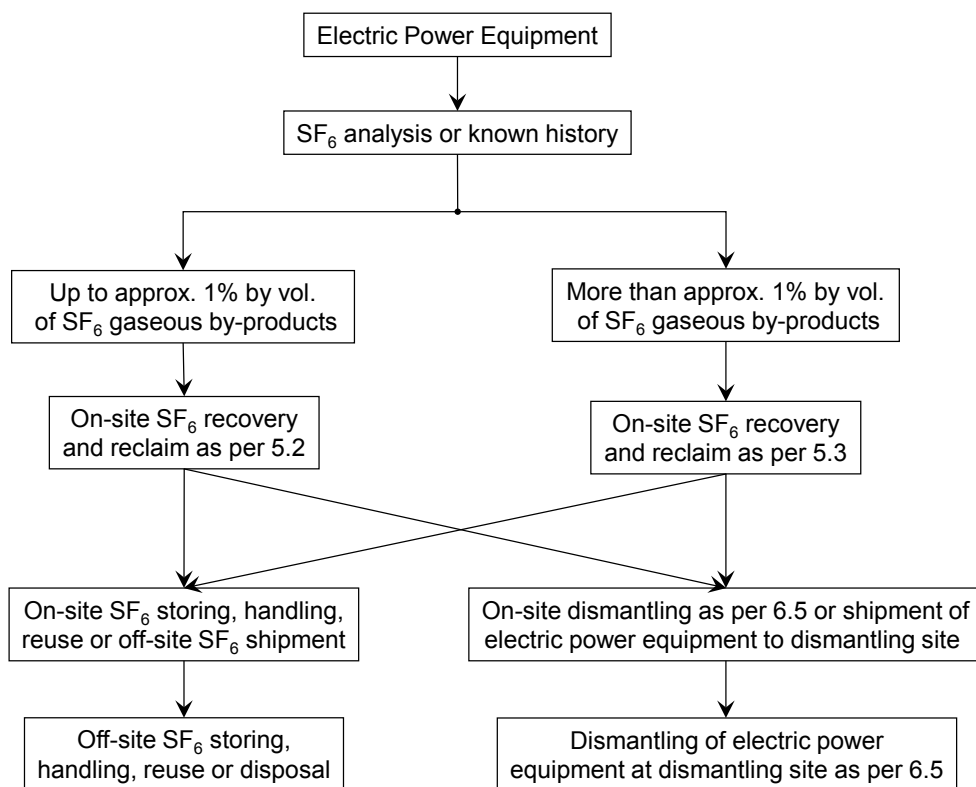
End-of-life dismantling is performed according to local regulations under the Owner / User's responsibility and supported by the Original Equipment Manufacturer as his knowledge and experience are essential. Third parties, such as qualified service companies, may also carry out end-of-life dismantling. 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 SF₆, 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.



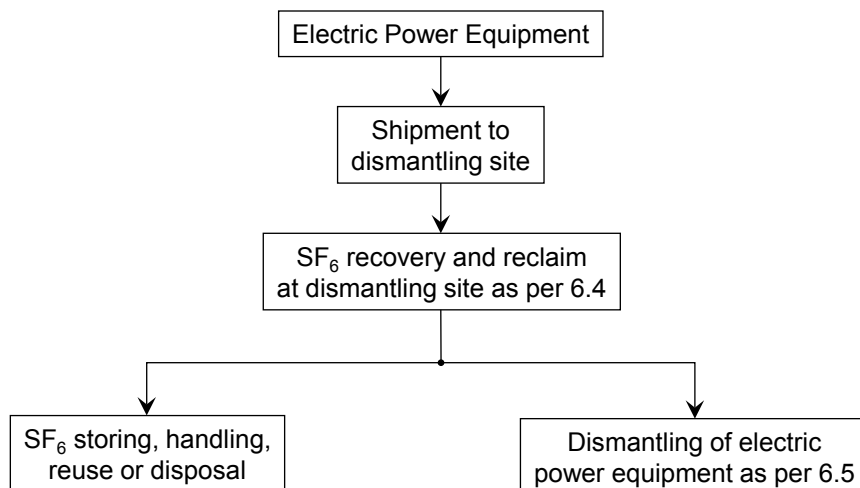
IEC 2096/13

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 SF₆ 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, SF₆ recovery and dismantling could be performed on-site. The procedure for SF₆ recovery remains the same and is reported in 6.4.



IEC 2097/13

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

Sealed pressure systems may be shipped to the dismantling site before removal of SF₆, 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 SF₆ 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 SF₆ recovery and reclaim at the end-of-life of sealed pressure systems

SF₆ 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 SF₆ recovery. If not, then tight drilling systems shall be used.

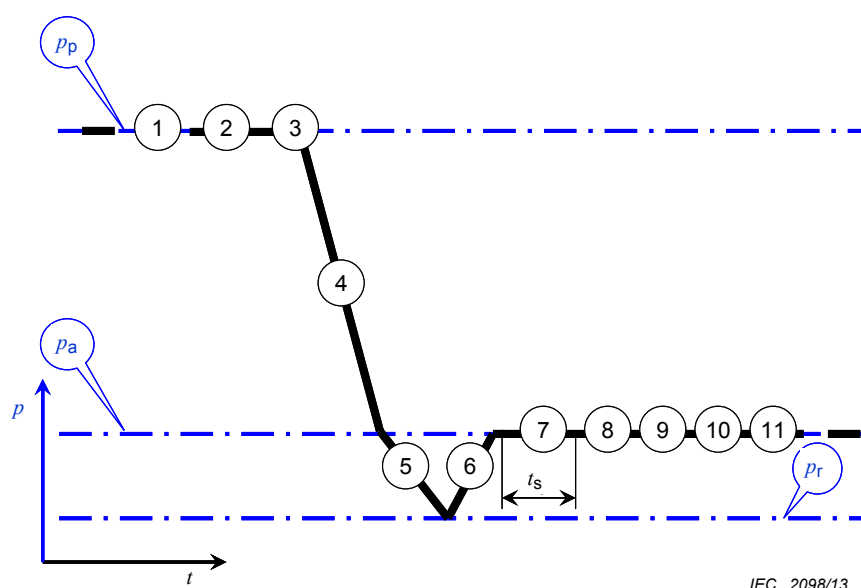
The partial SF₆ pressure in the gas compartment prior to opening shall be lower than 2 kPa.

Figure 10 and Table 8 can be adopted as an example of the detailed sequence of operations for SF₆ 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 SF₆ 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 SF₆ pressure of 2 kPa (e.g. dilution method) in the gas compartment prior to opening.

NOTE The partial SF₆ pressure is the pressure of SF₆ occupying alone the whole volume of the gas compartment. For pure SF₆ if the procedure detailed in Figure 10 and Table 8 is followed, SF₆ is the only gas in the gas compartment and therefore the partial SF₆ pressure is practically equal to the SF₆ residual pressure.

The safety rules given in Annex B should be followed.



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

Figure 10 – SF₆ recovery and reclaim at the end-of-life of sealed pressure systems

Table 8 – SF₆ 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.

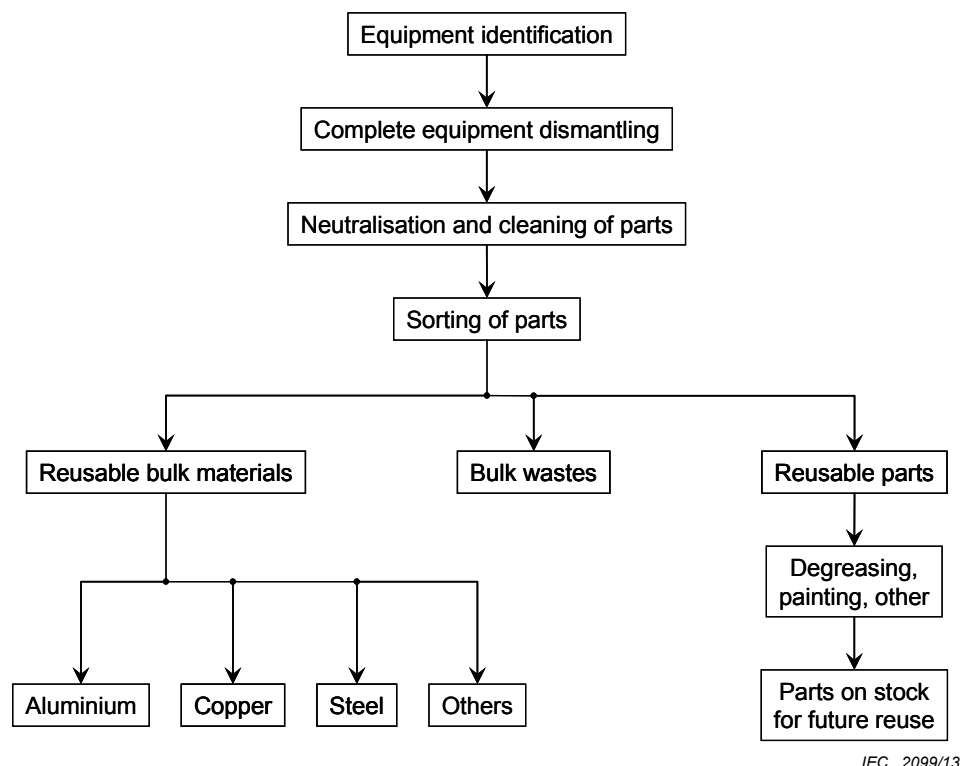


Figure 11 – Dismantling of electric power equipment

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 SF₆ 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 SF₆ 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 SF₆ characteristics and quantity of by-products for various types of electric power equipment are given in Table 9.

Table 9 – Expected SF₆ 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 disconnecter	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 SF₆

A.1 General

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

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

A.2 Storage of containers filled with SF₆

In general SF₆ can be stored in two ways either as a gas at less than 2 MPa or as a liquid up to 5 MPa. Gaseous storage has the advantage of reducing the recovery and filling times but requires large storage volumes and is therefore generally restricted to small volume equipment or used in fixed location gas handling facilities. Liquid storage gives the ability to reduce storage volumes and economically transport large quantities of SF₆.

Containers 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 SF₆ and used SF₆ suitable for reuse on site should be physically separated from those containing used SF₆ suitable for reuse at the gas manufacturer or used SF₆ not suitable for reuse.

Table 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 SF₆

Method	Requirements	Features
Gaseous	Typical pressure lower than 2 MPa. SF ₆ remains in the gaseous state	Requires relatively small recovery pressure differential (typically 100:1) but needs larger storage volumes. Gas cannot be liquefied in containers for transportation. Therefore it is limited to small quantities (typically 200 kg) and stationary use
Liquid-Cooling Assisted	Typical pressure equal to 3 MPa. Employs additional cooling system to cool SF ₆ after compression, which allows SF ₆ to be stored in liquid form	Requires relatively small recovery pressure differential (typically 700:1) but needs cooling aggregate. Performance of cooling aggregate can influence processing speed. Additional maintenance requirements. Limited storage volume required and generally not suitable for transportation
Liquid-Pressure Only	Typical pressure equal to 5 MPa. SF ₆ compressed to 5 MPa liquefies by pressure only	Requires recovery differential of typically 1 000:1 but eliminates the need of additional aggregates. Can be used with any storage vessel rated 5 MPa or higher

When used SF₆ is stored on-site, the storage containers 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 SF₆

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. NOTE The filling factor for technical grade SF ₆ is up to 1,04 kg/l. Recommendation: Containers should be marked with a green label or the container should be painted green according to EN 1089-3.	Stencilled on container: UN 1080, sulphur hexafluoride Danger label 2.2
Used SF ₆ suitable for reuse on site	Liquefied inert gas	Suitable for liquefied gas up to a pressure of 7 MPa. NOTE: Due to the inert gas content (e.g. N ₂ , O ₂), the filling factor is smaller than 0,8 kg/l. ^b 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 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 9}	
	Liquefied gas containing toxic gaseous by-products ^d	Same as for used SF ₆ suitable for reuse on site ^{f 9}	Stencilled on container: UN 3162, sulphur hexafluoride, hydrogen fluoride, thionyl fluoride ^c 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 9}	Stencilled on container: UN 3308, sulphur hexafluoride, hydrogen fluoride, thionyl fluoride 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 SF₆ 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 SF₆ containing toxic gaseous by-products can be reclaimed on site to remove the toxic gaseous by-products thereby facilitating easier transportation. ^e Any used SF₆ containing both toxic and corrosive gaseous by-products can be reclaimed on site to remove the toxic and corrosive gaseous by-products and allowing an easier transportation. ^f Containers filled with used SF₆ suitable for reuse at gas manufacturer should be tagged with the following sentence: "Contains used SF₆ suitable for reuse at gas manufacturer". ⁹ Containers filled with used SF₆ not suitable for reuse should be tagged with the following sentence: "Contains used SF₆ not suitable for reuse".			

A.3 Transportation of containers filled with SF₆

International regulations for shipment of electric power equipment containing SF₆ and SF₆ containers are available for transportation by road (ADR), rail (RID), ship (IMDG Code), and

air (IATA – DGR). These are similar concerning UN numbering, classification, danger labelling, final classification, and transport documentation. However official languages differ as follows:

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

The international regulations for shipment of SF₆ are summarised in Table A.3.

Table A.3 – International regulations for shipment of SF₆

Gas	Characteristic	Class	Final classification ^a	Transport document ^a
Technical grade SF ₆ ^b	Liquefied inert gas	2A	UN 1080 liquefied gas, n.o.s. 2.2	UN 1080 liquefied gas, n.o.s (sulphur hexafluoride) 2.2
Used SF ₆ suitable for reuse on site	Liquefied inert gas	Transportation class and danger label are the same as for technical grade SF ₆	UN 3163 liquefied gas, n.o.s. 2.2	UN 3163 liquefied gas, n.o.s. (sulphur hexafluoride and air or nitrogen or carbon tetrafluoride) 2.2
Used SF ₆ suitable for reuse at gas manufacturer or used SF ₆ not suitable for reuse	Liquefied inert gas	UN number, transportation class, danger label, final classification and transport document are the same as for used SF ₆ suitable for reuse on site		
	Liquefied toxic gas (gas containing toxic gaseous by-products) ^c	2T	UN 3162 liquefied toxic gas, n.o.s. 2.3	UN 3162 liquefied gas, toxic, n.o.s. (sulphur hexafluoride and hydrogen fluoride and thionyl fluoride) 2.3
	Liquefied toxic and corrosive gas (gas containing both toxic and corrosive gaseous by-products) ^d	2TC	UN 3308 liquefied toxic and corrosive gas, n.o.s. 2.3 + 8	UN 3308 liquefied gas, toxic, corrosive, n.o.s. (sulphur hexafluoride and hydrogen fluoride and thionyl fluoride) 2.3 + 8
^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 SF₆

Electric power equipment filled with SF₆ shall be stored and transported according to local and international regulations.

A.5 Responsibilities

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

Table B.1 – Measures when working with SF₆ 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 SF₆ is being handled in any location.

When a gas compartment is opened after the electric power equipment has been in service, in order to avoid contact with the fine solid by-products, which may be present, personnel should wear suitable protective clothing. Particular attention should be given to protecting the eyes and the respiratory tract. Personnel working in or near to opened gas compartments, which have contained normally arced or heavily arced SF₆ 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

SF₆ is handled by certified personnel, only. Different training modules may be adopted, depending on the kind of work to be performed on the electric power equipment (see Annex C).

A specific training covering the recovery of used SF₆ 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-arc'd SF ₆
Potential risk	Fumes of cleaning substances O ₂ starvation Remaining used SF ₆ Residual reactive gaseous by-products Solid by-products and adsorber materials	Fumes of cleaning substances O ₂ starvation Remaining used SF ₆ or other gas from production process
Safety precaution	Removal of solid by-products and adsorber materials Ventilation Measurement of O ₂ concentration when entering Wear personal protective equipment Protect solid by-products against hydrolysis	Ventilation Measurement of O ₂ concentration before entering
Safety equipment and tools	Suction ventilator or vacuum cleaner O ₂ concentration measuring device Single use protective overalls, protective footwear, hair cap Acid proof safety gloves Full face mask (preferred) or, at least, breathing protective mask Protective goggles Environmental protection against rain or wind (outdoor only)	Suction ventilator or vacuum cleaner O ₂ concentration measuring device

Like any gas but oxygen, a concentration greater than 190 ml/l (19 % by volume) of SF₆ 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 bibliogra- phy
Lime	Ca(OH) ₂	Saturated	Not applicable	24	[9]
Sodium carbonate (washing soda)	Na ₂ CO ₃	1,1 3 10 ^c 10-14 ^c 3	Not applicable Wash not applicable 1 not applicable	24 not applicable 0,25 48 not applicable	[10] [9] [11] [12] [13]
Sodium bicarbonate	NaHCO ₃	1 ^d	Not applicable	not applicable –	[11]
^a Reusable safety equipment, tools, gas compartments, and internal parts of compartments which contained normally arced SF₆ should, where practicable, be treated with a neutralising solution for a time period T₁. They should then be rinsed with clean water. ^b Reusable safety equipment, tools, gas compartments, and internal parts of compartments which contained heavily arced SF₆ should, where practicable, be treated with a neutralising solution for a time period T₂. 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 SF₆ handling potentially contain gaseous or liquid SF₆ 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 SF₆ 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 SF₆ 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 SF₆ 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 O₂ or the amount of by-products are at unsafe levels, a respirator is used according to local regulations (e.g. European Standard EN 136);
- O₂ concentration measurement device for permanent monitoring of the O₂ 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 SF₆ 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 SF₆ due to external fire or internal arc

General safety recommendations to adopt when working with SF₆ on site are given in B.1. This B.2 describes additional safety measures in case of abnormal release of SF₆ due to external fire or internal arc fault.

Under these circumstances, personnel trained on modules C1 or C2 (see clauses C.2.5 and 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-arc'd or normally arced SF ₆
Potential risk	Fumes of cleaning substances O ₂ starvation SF ₆ abnormally released Residual reactive gaseous by-products Solid by-products	Fumes of cleaning substances O ₂ starvation SF ₆ abnormally released
Safety precaution	Removal of solid by-products Ventilation Measurement of O ₂ concentration when entering Wear personal protective equipment	Ventilation Measurement of O ₂ concentration when entering
Safety equipment and tools	Suction ventilator or vacuum cleaner O ₂ concentration measuring device Single use protective clothes, shoe covers, hair cap Acid proof safety gloves Full face mask (preferred) or, at least, breathing protective mask and protective goggles	Suction ventilator or vacuum cleaner O ₂ concentration measuring device

The same rules apply to areas below the level at which the release occurred, poorly ventilated or unventilated areas (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 O₂ 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 SF₆, 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 SF₆.

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

No prerequisites are requested for attending the training.

All personnel working in the proximity to SF₆ 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 SF₆ emissions and mitigation approaches [19];¹
- physical, chemical and environmental characteristics of SF₆ (see Annex E);
- use of SF₆ 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);
- SF₆ 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 SF₆ quality on-site;
- perform a SF₆ 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;
- SF₆ quality according to IEC 60376 (technical grade SF₆) and IEC 60480 (SF₆ 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 SF₆ filled compartments (see 2.9, 2.10, 2.11, and 2.12);

¹ Numbers in square brackets refer to the Bibliography.

- instruments and procedures for checking the SF₆ 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 SF₆ 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 SF₆ (see Annex A);
- monitoring of SF₆ 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 SF₆ filling (see 3.2);
- procedures for topping-up with SF₆ (see 3.3);
- procedures for recovery and reclaim of non-arc'd SF₆ (see 5.2);
- SF₆ 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 SF₆, 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 SF₆ due to fire or internal arc fault (see B.2);
- procedures for recovery and reclaim of normally and heavily arc'd SF₆ (see 5.3).

- SF₆ 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 SF₆ 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. SF₆ recovery);
- restrict task performance (e.g. SF₆ 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 SF₆ Handling Equipment

D.1 General

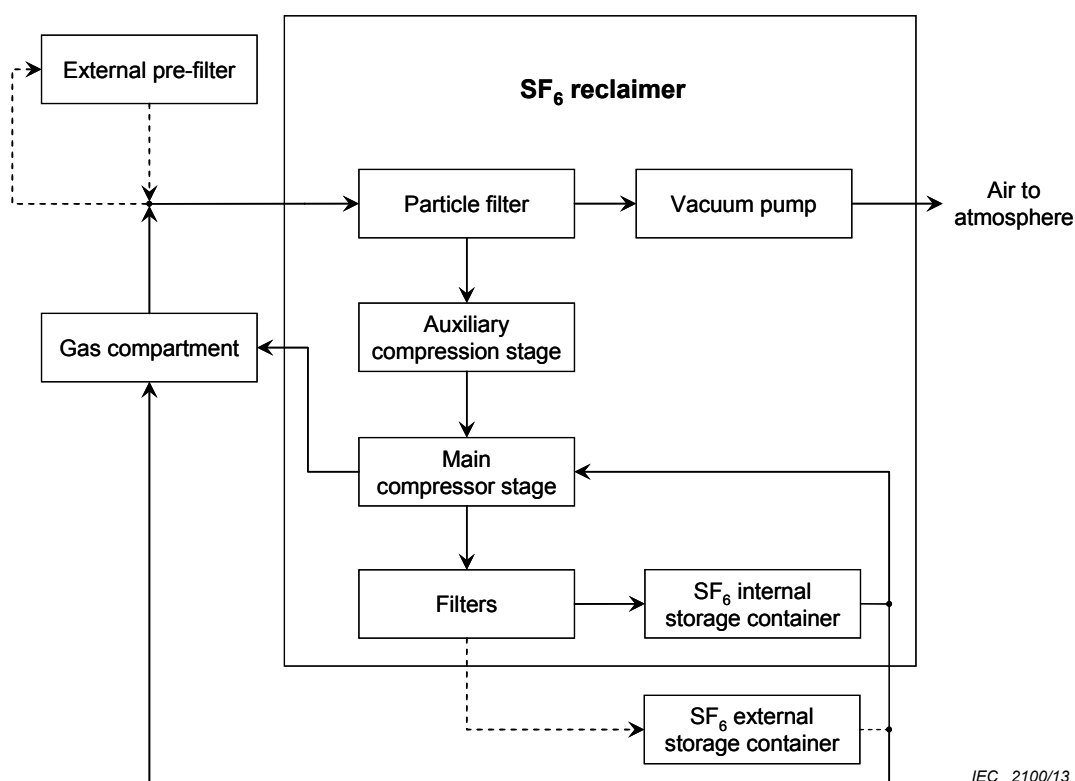
This annex gives information about minimum functionality and performance criteria for SF₆ handling equipment and specific components.

D.2 Reclaimer

D.2.1 General

The appropriate type and size of the reclaimer should be chosen according to the SF₆ 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 SF₆ in the gas compartment;
- recovery of SF₆ from the gas-filled compartment;
- storage and filtering of SF₆;
- flooding of the gas compartment with ambient air;
- cylinder to cylinder (or storage tank) transfer.



IEC 2100/13

Figure D.1 – General purpose reclaimer

D.2.2 External pre-filters

An external pre-filter is required to recover used SF₆. 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 SF₆ 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 SF₆ in a container, hence allowing for its reuse. These filters are installed in the reclaimer.

Table D.1 shows typical filter types used during SF₆ reclaim.

Table D.1 – Typical filter types used during SF₆ 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. Residual SO ₂ +SOF ₂ lower than 12 µl/l. 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 (NaCO₃) should not be used as a filter material for SF₆ as, upon contact with certain reactive gaseous by-products, produces CO₂, which is difficult to remove from SF₆.

D.2.3.4 Oil filter

An oil trap should be inserted in the SF₆ cycle if an oil-lubricated machine is used or if an oil-insulated electric component is included in the electric power equipment utilising SF₆. 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 SF₆, typically air or N₂ to avoid SF₆ 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 SF₆ – 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 SF₆ 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 SF₆ in a gaseous form (5 MPa pressure is recommended). An additional cooling device can be used to speed up SF₆ recovery.

D.2.6 External and internal gas storage containers

Commercial pressure vessels or special storage containers for used SF₆ 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 SF₆ 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 SF₆ storage a nominal pressure of 5 MPa is used.

D.2.7 Evaporator and gas storage container heater

If SF₆ is stored in liquid form and used as a gas, thermal losses due to evaporating inside the container can cause SF₆ 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 SF₆ 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 SF₆ cycle for pressure relief. Local safety regulations are followed. Safety valves, which do not directly release SF₆ 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: -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 SF ₆ percentage SF ₆ /CF ₄	0 ml/l to 1 000 ml/l	-20 °C to 40 °C	±10 ml/l ±20 ml/l
Analysers of reactive gaseous by-products	By-products as e.g. SO ₂ Oil mist	1 µl/l to 25 µl/l 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 SF₆ 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 SF₆ 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 SF₆ 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 SF₆ percentage measuring device

Devices that compare the speed of sound or the thermal conductivity of the SF₆ gas mixture with pure SF₆ are used to determine the SF₆ percentage. Velocity of sound based systems