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GUIDE FOR THE PREPARATION OF CUSTOMISED "PRACTICAL SF_6 HANDLING INSTRUCTIONS"

Task Force
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Members and Contributors

P Glaubitz (Convenor), S Stangherlin (Secretary),
D Crawley, J Henriot, A Holm, P Jannick, P Justiz, M Meguro,
R Probst, P Sieber, S Theoleyre, T Yokota, L Van der Zel

SUMMARY

This document reviews all significant aspects in handling SF_6 gas used in electric power equipment.

Among all, gas recovering, reclaiming and recycling have fundamental importance in order to keep the gas permanently in a closed cycle, avoiding any deliberate release and preserving the environment. State-of-the-art technologies and procedures are described and suggested to minimize SF_6 emissions down to the minimum functional level for the electric power equipment.

All possible aspects that may be encountered during the whole life of electric power equipment are covered:

- Commissioning or re-commissioning
- Topping-up
- Re-filling
- Checking gas quality on-site
- Sampling and shipment for off-site gas analysis
- Recovery and reclaiming
- Recovery and reclaiming at the end-of-life when the electric power equipment is dismantled

State-of-the-art tools and measuring devices as well as the necessary personal protection equipment are given.

The chapters are individually prepared and complete themselves and therefore can be used to compile a customized operating manual for “Practical SF_6 Handling Instructions”.

This is the first edition of the guide.

SF_6 tightness of electric power equipment will be covered in a separate document, which is at the planning stage for the time being.

Contents

1 INTRODUCTION

The purpose of this document is to give practical recommendations for a customised "Practical SF_6 Handling Instruction Guide" that is specific to any equipment so that it becomes a standardized document containing standard information and procedures covering:

- Commissioning or re-commissioning;
- Topping-up;
- Re-filling;
- Checking gas quality on-site;
- Sampling and shipment for off-site gas analysis;
- Recovery and reclaiming;
- Recovery and reclaiming at the end-of-life when the electric power equipment is dismantled

The guide is organised in individual modules that can be bound together to form a customised "Practical SF_6 Handling Instructions" manual. Such a standard manual describes the SF_6 handling procedure, according to the state-of-the-art technique. It is recommended that this guide be strictly followed in order to achieve operational, safety at work and environmental benefits such as:

- Safe operation of the equipment;
- Optimisation of resources and tools required;
- Minimisation of out-of-service time for equipment;
- Standard training of personnel handling SF_6;
- Reduction of the amount of gas released during handling operations down to the functional physical limit;
- Avoidance of any deliberate release, e.g. flushing to the atmosphere;
- Reduction of SF_6 losses and emissions during commissioning, service and operation to a minimum.

2 DEFINITIONS

Pressure: pressures are given in terms of absolute units, either Pa or kPa.

Air evacuation: Air transfer from the electric power equipment to the atmosphere.

SF_6 recovery: SF_6 transfer from the electric power equipment into a reclaimer or a storage container.

Reclaimer: Device for purification of used SF_6 for the purpose of re-use.

Energised: Adjective. Qualifies a conductive part having an electric potential difference with respect to a relevant reference. The reference potential is usually earth or an equipotential frame.

Tight drilling system: When connection to SF_6 compartment via available openings (e.g. filling points, pressure gauge) is not provided, then a tight drilling system shall be used. This generally consists of a drill fitted with a hollow bit connected to hoses with appropriate gasket systems to avoid leakage during and after drilling.

3 GENERAL BACKGROUND MODULES

This section provides general background information organised as modules.

3.1 Gas characteristics

The following paragraphs give the main properties/characteristics of SF_6 gas.

3.1.1 General

Sulphur hexafluoride is a synthetic gas formed by 6 atoms of fluorine gathered around a centrally situated atom of sulphur.
The chemical formula is SF_6, the molecular weight is 146.05 g/mol and the gas is identified by CAS Number 2551-62-4.
The chemical bond between fluorine and sulphur is known as one of the most stable existing atomic bonds. Six of these grant the molecule very high chemical and thermal stability. In addition, the compatibility of SF_6 with material used in electric constructions is similar to that of nitrogen, up to temperatures of about 180 °C.

Since the early 1960's, SF_6 has been successfully used by the Electricity Industry in power equipment for the HV transmission and MV distribution of electricity (gas insulated substations, ring main units, circuit breakers, transformers, cables, etc.).
Other non-electrical industrial applications include metallurgy, electronics, scientific equipment, ocular surgery and military applications.

The **maximum tolerable moisture level** for the gas in the equipment is specified by IEC 60694 [5] (currently under revision, future 62271 - 1). Purity requirements for **SF_6** as it comes **from the supplier** are specified by IEC 60376 [2] (currently under revision). Purity requirements for **re-use of reclaimed SF_6** are specified by IEC 60480 [3].

3.1.2 Physical

Pure SF_6 is odourless, tasteless, non-toxic, non-corrosive, non-flammable and chemically inert at ambient temperature. It does not support combustion.

Although the gas is non-toxic, it does not support life, as it is not oxygen. Equipment containing SF_6 must not be entered without adequate ventilation and personal protection equipment.

Its solubility in water (7000 ppmv) is 4 times lower than that of air.

3.1.3 Thermodynamic

At normal room temperatures and pressures (20 °C and 100 kPa) SF_6 is about 5 times heavier than air (density: 6.07 kg/m^3).

As the gas is heavier than air, areas below ground level, poorly ventilated or unventilated areas (i.e.: cable ducts, trenches, inspection pits, drainage system, etc.), may remain full of SF_6. Personnel must be aware of the danger of asphyxiation in such places.

As the critical temperature and pressure of SF_6 are 45.54 °C and 3.759 MPa respectively, it can be liquefied by compression and is usually transported as a liquid in cylinders or containers.

As the gas is delivered in the form of compressed liquid, if large quantities of the gas are released rapidly, the temperature of both the gas and the container fall quickly. Frost and ice may form on metal parts. If this occurs, gas filling has to be immediately stopped until ice and frost are gone. Filling of SF_6 must always be performed slowly. Personnel must be aware of the danger of freeze burns when touching iced and/or frozen metal parts.

The heat capacity of one mole of SF_6 is around 3 times greater than air.

3.1.4 Electric

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

3.1.5 Environmental

SF_6 does not harm the ecosystem: biological accumulation in the food chain does not occur. It is an inert gas with very low solubility in water so that it presents no danger to surface and/or ground water and/or the soil.

SF_6 has no impact on the stratospheric ozone layer (Ozone Depletion Potential – ODP = 0), but it is a potent (Global Warming Potential – GWP = 22500 - 22200 times CO_2) and persistent (Atmospheric Life Time – ALT = 650 - 3200 years) greenhouse gas [10], [9]. The difference in the figures is a consequence of the adoption of different calculation models.

The GWP of SF_6 alone is not adequate to measure the environmental impact of electric power equipment based on SF_6 technology. The environmental impact of any specific application shall be evaluated and/or compared using the Life Cycle Assessment – LCA approach as regulated by ISO 14040 [8].

SF_6 has to be used in a closed cycle. When gas removal from containment is needed, a proper handling procedure shall be implemented to avoid any deliberate release into the atmosphere.

The yearly SF_6 emission rate from the overall Electric Industry represents 0.1% of the yearly emission rate of man-made global warming gases. As just one example, emissions from European manufacturers and users contribute only by 0.008%.

The impact on global warming due to the SF_6 concentration in the atmosphere (atmospheric burden) is approximately between 0.01 and 0.02% of the overall green-house effect.

3.2 Characteristics of the electric power equipment

The main applications in electric power equipment utilising SF_6 are defined by the current IEC Standards in force: 62271-200 for MV equipment, 62271-203 for HV equipment, 60694 for common specifications (currently under revision; it will become 62271-1), 62271-100 as well as 62271-102 for circuit breakers and disconnectors, respectively.

The tightness of certain old installed gas insulated power equipment, especially for HV systems, could be a significant issue for environmental impact. **Nevertheless, it has to be kept in mind that handling SF_6 during installation, on site testing and maintenance activities may contribute significantly to the overall emissions.**

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

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

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

3.2.1 Controlled pressure systems

A volume automatically replenished from an external or internal gas source. The volume may consist of several permanently connected gas-filled compartments.
Controlled pressure systems are no longer used in new equipment, because of their high leakage rate.
It is recommended that controlled pressure systems in old equipment are replaced by closed pressure systems, because of the unacceptable leakage rate.

3.2.2 Closed pressure systems

A volume replenished only periodically by manual connection to an external gas source. High Voltage (above 72,5 kV) SF_6 single pressure circuit breakers are examples of closed pressure systems.

In spite of the fact that **state-of-the-art HV electric power equipments are closed pressure systems**, their typical time between two consecutive maintenance operations is around 25 years. In practice, on-site SF_6 handling is already minimized, as it is only required for installation, extension and/or end-of-life-disposal/dismantling of equipment.
It is recommended that:

- **The leakage rate is kept lower than 0.5% p.a. per gas compartment;**
- **The typical time between two consecutive maintenance is up to 25 years;**
- **The SF_6 conditions are checked only after a filling operation;**
- **Appropriate record – keeping procedures are used.**

3.2.3 Sealed pressure system

A volume for which no further gas or vacuum processing is required during its expected operating life. Sealed pressure systems are completely assembled and tested in the factory.

State-of-the-art MV electric power equipments are sealed pressure systems. They are commercially designated "sealed for life", as they require no on-site gas handling for their whole life duration, typically 40 years. End-of-life-disposal is performed under the responsibility of the user and is supported by the manufacturer. Third parties, such as service companies, may also carry out end-of-life disposal.

As SF_6 is handled only twice, for gas filling at the beginning and for gas recovery at the end, during the whole product life and this is done in a controlled environment, handling losses can be considered to be of the same order of magnitude of leakage losses. Today a typical leakage rate is lower than 0.1% p.a. per gas compartment.

3.2.4 Description of the installed system

Among all characteristics defined by the current IEC Standards in force and given in the instruction manual from the manufacturer, those most relevant to SF_6 handling are highlighted in Table 1. They are, at least:

Table 1: The most relevant characteristics of electric power equipment concerning SF_6 handling

Closed pressure systems	Sealed pressure systems
SF_6 mass per compartment/substation in kg	
Volume per compartment/substation in litres or m^3	
Rated SF_6 filling pressure at 20 °C in kPa or bar	
Leakage rate in % p.a. per gas compartment	
Designation of different compartments: breaker, disconnector, bus-bar, etc.	
Number of separate compartments	
Location of safety overpressure control means	
System used to observe the pressure in each containment	When relevant
Precautions when handling SF_6 containments	Not relevant
Record- keeping	When relevant
Typical time between two consecutive maintenance in years	No maintenance required
Typical time between two consecutive SF_6 measurements in years	No SF_6 checking required
Location of SF_6 valves	When relevant
Location of gas tight spacers	When relevant
Pressure levels of alarms/indicators in kPa or bar, number of steps	When relevant

It is recommended that reference be made to the SF_6 switchgear instruction manual provided by the manufacturer.

3.2.5 Description of the monitoring system for controlled and closed pressure systems

In order to operate safely, switchgear needs a minimum gas pressure/density. In the case of controlled or closed pressure systems, visual indications and/or acoustic alarms are set as a function of that threshold. If the gas pressure/density reaches its minimum threshold, standard operations can no longer be maintained and, according to specific users requirements, appropriate counter measures (e.g.: alarm, automatic lockout, switching features) come into effect.

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

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

State-of-the-art monitoring systems continuously monitor gas pressure/density allowing for early detection of small leaks.

In addition to the above, appropriate corrective measures to locate and eliminate the leak shall be immediately arranged.

3.3 Environmentally compatible SF_6 policy

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

Voluntary agreements [14] involving manufacturers and users have been signed in some countries with the aim of controlling and reducing emissions of SF_6 from the electric power equipment. In general, it is mentioned in such agreements that for the development, manufacturing, installation, operation, maintenance and end-of-life disposal of SF_6 electric power equipment, state-of-the-art technologies and procedures are applied to minimize SF_6 emissions.

Among all, the following voluntary actions are typically performed:

- Systematic re-use, reprocessing and final disposal of SF_6 as a closed cycle process;
- Monitoring of SF_6 - filled gas compartments to ensure that leaks are detected and eliminated at an early stage, in controlled and closed pressure systems;
- Manufacturers of controlled and closed pressure systems produce and guarantee electric power equipment with a leakage rate lower than 0.5% p.a. for each compartment (for new equipment produced);
- Manufacturers of sealed pressure systems provide electric power equipment with a leakage rate lower than 0.1% p.a. for each compartment (for new equipment produced);
- SF_6 recovered from electric power equipment on-site is, as far as possible re-used directly on-site. Non-reusable SF_6 is kept in a closed cycle for further processing off-site;
- SF_6 producers take back non-reusable SF_6 and re-process it or reduce it to environmentally compatible end products;
- Personnel handling SF_6 are regularly instructed so that SF_6 is only handled by properly qualified personnel;
- Producers of SF_6 keep statistics of the SF_6 quantities produced and sold. Users of SF_6 in the electric industry record their SF_6 consumption and inventories;
- SF_6 producers and professional associations of manufacturers/users of electric power equipment utilising SF_6 provide the authorities SF_6 relevant statistical data as basis for regional/national SF_6 monitoring.

If SF_6 handling is performed as described above, life cycle assessment studies (LCA) demonstrate that SF_6 technology applied to power electric equipment minimises the impact on the environment [15] [16].

State-of-the-art SF_6 technology is compatible with the environment, as the concrete voluntary actions listed above are considerably reducing SF_6 emissions down to the functional physical limit.

3.4 Toxicity

Pure SF_6 is not toxic (see paragraph 3.1.2).
Toxic gaseous and/or solid decomposition products may arise during the operation of gas insulated electric equipment. They are fully described in a previous CIGRE document [12] and also in IEC Technical Report 61634 [6].
Design rules and operational procedures are implemented to handle both the gas and the equipment according to safety rules to eliminate any potential harmful effects.

3.5 Gas categories

Sulphur hexafluride contains contaminants. These originate from the industrial manufacturing process as well as from use of the gas in electric power equipment. Depending on the nature and the amount of the contaminants, the following gas categories have been defined:

- New gas or technical grade SF_6;
- Non-arced gas;
- Normally arced gas;
- Heavily arced gas;
- Gas suited for the complete range of use pressures;
- Gas suited for the low range of use pressures;
- Gas not suited for re-use.

The following paragraphs give more details.

3.5.1 New gas or technical grade SF_6

Gas supplied in cylinders, tagged with the “green collar”, as provided by the SF_6 producer/supplier and complying with a standard on SF_6 for use in electric equipment such as IEC 60376 ed. 1 (new gas) or the near future ed. 2 (technical grade gas) [2].
The maximum acceptable impurity levels for new gas and technical grade SF_6 are given in Table 2 and Table 3, respectively.

Table 2: Maximum acceptable impurity levels for new gas (IEC 60376 ed. 1)

Impurity	Specification
Air	0.05 % w
CF_4	0.05 % w
H_2O	15 ppmw
Mineral oil	see note
Total acidity expressed in HF	0.3 ppmw
Hydrolysable fluorides, expressed as HF	1.0 ppmw
Note: SF_6 shall be substantially free from oil. The maximum permitted concentration of oil and the method of measurement are under consideration.	

Table 3: Maximum acceptable impurity levels for technical grade SF_6 (FDIS IEC 60376 ed. 2)

Impurity	Specification
Air	0.2 % w [note 1]
CF_4	2400 ppmw [note 2]
H_2O	25 ppmw [note 3]
Mineral oil	10 ppmw
Total acidity expressed in HF	1 ppmw [note 4]
Note 1: 0,2% w is equivalent to 1% v under ambient conditions (100 kPa and 20 °C). **Note 2**: 2400 ppmw is equivalent to 4000 ppmv under ambient conditions (100 kPa and 20 °C). **Note 3**: 25 mg/kg (25 ppmw) is equivalent to 200 ppmv (200 µl/l) and to a dew point of –36 °C, measured under ambient conditions (100 kPa and 20°C). **Note 4**: 1 ppmw is equivalent to 6 ppmv measured under ambient conditions (100 kPa and 20°C).	

Due to the maximum impurity levels that can be present in SF_6, the SF_6 amount in a container (measured in the liquid phase) shall be higher than 99.7 %.

3.5.2 Non-arced gas

Gas that has been handled in any way and has not experienced arcing. In practice, if the **volume concentration** of the indicator gases **SO_2 + SOF_2 is lower than 100 ppmv**, then the gas is non-arced. Non-arced gas is to be expected at:

- Insulation testing in the factory;
- Insulation testing on-site during erection/commissioning;
- Routine maintenance of insulation compartments;
- Repair of insulation compartments after malfunction without arcing;
- Retrofitting of insulation compartments;
- Decommissioning of insulation compartments in which arcing has not occurred;
- Any kind of compartment after filling prior to energizing.

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

3.5.3 Normally arced gas

Gas recovered from switchgear compartments after normal switching operations. In practice, if the **volume concentration** of the indicator gases **SO_2 + SOF_2 is between 100 ppmv and 1%**, then the gas is normally arced. Normally arced gas is to be expected at:

- Maintenance and repair of switching devices after normal (load or fault) operation;
- Interruption testing during switchgear development;
- Decommissioning of switchgear.

Normally arced gas may contain, in addition to air and moisture:

- The inert gas CF_4 generated by arc erosion of polymers;
- Corrosive gaseous decomposition products up to about a few 100 ppmv as residues which have not been removed by adsorbers;
- Solid decomposition products, mainly metal fluorides and tungsten oxifluorides, usually referred to as "switching dust".

3.5.4 Heavily arced gas

Gas recovered from equipment in which failure arcing has occurred. In practice if the **volume concentration** of the indicator gases **SO_2 + SOF_2 is greater than 1%**, then the gas is heavily arced. Heavily arced gas is to be expected from:

- Circuit breakers after interruption failure;
- Insulation compartments after internal arcing failure;
- Any kind of arcing failure.

In this case, high levels of solid and gaseous contaminants have to be expected. The gaseous contaminants may reach levels of several % vol, of which a substantial fraction can be highly reactive and toxic and/or corrosive. The solid contaminants will generally be charged with adsorbed reactive gaseous contaminants.

3.5.5 Suited for the complete range of use pressures

Used SF_6 gas, stored in cylinders tagged with the “orange collar”, complying with a standard for used gas such as IEC 60480 [3], which can be re-used in any electric power equipment without any limitations.

The maximum acceptable impurity levels are given in Table 4.

Table 4: Maximum acceptable impurity levels for re-use of SF_6 – complete range of use pressures (IEC 60480)

Impurity	Specification
Air and/or CF_4	3% volume [note 1]
H_2O	25 ppmw [notes 2 and 3]
Mineral oil	10 ppmw [note 4]
Total reactive gaseous decomposition products	50 µl/l total or 12 µl/l for (SO_2+SOF_2) or 25 µl/l HF

Note 1: In case of SF_6 mixtures, the equipment manufacturer shall specify the levels for these gases.
Note 2: Converted to ppmv these levels shall also apply to mixtures until a suitable standard becomes available.
Note 3: 25 mg/kg (25 ppmw) is equivalent to 200 ppmv (200 µl/l) and to a dew point of -36 °C, measured at 100 kPa and 20 C.
Note 4: If gas-handling equipment (pump, compressor) containing oil is used, it may be necessary to measure the oil content of the SF_6. If all equipment in contact with the SF_6 is oil-free, then it is not necessary to measure oil content.

3.5.6 Suited for the low range of use pressures

Used SF_6 gas, stored in cylinders tagged with the “orange collar”, complying with a standard for used gas such as IEC 60480 [3], which can be re-used in any electric power equipment having the SF_6 rated filling pressure not exceeding a certain limit, e.g. 200 kPa. The maximum acceptable impurity levels are given in Table 5.

Table 5: Maximum acceptable impurity levels for re-use of SF_6 – low range of use pressures (IEC 60480)

Impurity	Specification
Air and/or CF_4	3% volume [note 1]
H_2O	95 ppmw [notes 2 and 3]
Mineral oil	10 ppmw [note 4]
Total reactive gaseous decomposition products	50 µl/l total or 12 µl/l for (SO_2+SOF_2) or 25 µl/l HF

Note 1: In case of SF_6 mixtures, the equipment manufacturer shall specify the levels for these gases.
Note 2: Converted to ppmv these levels shall also apply to mixtures until a suitable standard becomes available.
Note 3: 95 mg/kg (95 ppmw) is equivalent to 750 ppmv (750 µl/l) and to a dew point of –23 °C, measured at 100 kPa and 20 °C.
Note 4: If gas-handling equipment (pump, compressor) containing oil is used, it may be necessary to measure the oil content of the SF_6. If all equipment in contact with the SF_6 is oil-free, then it is not necessary to measure oil content.

3.5.7 Not suited for re-use

Used SF_6 gas not complying with a standard for used gas such as IEC 60480 [3]. This gas requires further treatment, usually off-site and/or eventually final disposal.

3.6 Safety during on site SF_6 handling

Before starting any maintenance/service work in SF_6 power equipment, the detailed state/condition of the equipment must be inspected and reported in detail.

The following general safety rules have to be fulfilled:

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

Written documents giving permission to work on/energize equipment shall be agreed and signed by both the owner of the equipment and the service provider.

For environmental aspects and safety reasons, topping up of leaking energised compartments is not recommended and therefore it is not covered in the present document.

3.6.1 General safety rules and recommendations

Table 6 lists the major issues to consider when working on SF_6 switchgear.

Table 6: General measures when working with SF_6-switchgear.

Item	**Work in the vicinity of switchgear (operation of SF_6-switchgear, visual check, room-cleaning)**	**Filling, recovering, evacuation of SF_6 gas-compartments**	**Opening of SF_6 gas-compartments, work on open compartments**
SF_6 material safety data sheet/operational manuals		Mandatory	Mandatory
Training	Mandatory [note]	Mandatory	Mandatory
Gas handling equipment		Mandatory	Mandatory
Cleaning/ neutralising equipment			Mandatory
Personal protection equipment			Mandatory
Flames		Not allowed	Not allowed
Welding/Smoking		Not allowed	Not allowed
Drinking/Eating			Not allowed
Note: General information must be specified according to type of work and installation.			

In addition to paragraphs 3.1.2 and 3.1.3, like any gas but oxygen, a concentration greater than 19% of SF_6 in the air is considered as potential risk of asphyxiation. This is because it reduces the oxygen concentration down to 16%, which is usually considered as the clinical threshold for asphyxiation. As a consequence it is recommended that the oxygen content in the gas compartment be measured prior to entering/accessing. In addition to that, the oxygen content in the ambient may be checked when working in confined spaces.

Switching dust, which might be present inside the gas compartment after opening, as well as the adsorbers (or filters), contain acidic compounds and must be treated as special chemical waste according to local regulations. This applies also to any tool/equipment (i.e. vacuum cleaner, cleaning paper, protective clothes), which has been in contact with the switching dust.

3.6.2 Protection of personnel

Safety measures are mandatory when accessing and/or entering a gas compartment. The type and extent of protection depend on the category of the gas in the compartment (see paragraph 3.5). Details are given in Table 7.

Table 7: Safety at work when accessing/entering gas compartments in electric power equipment utilizing SF_6

Item	**Open compartment before first SF_6 filling**	**Open compartment which contained non-arced SF_6**	**Open compartment which contained either normally arced or heavily arced SF_6**
Potential risk	• Fumes of cleaning material • O_2 starvation • Remaining SF_6 or other gas from production process	• Fumes of cleaning material • O_2 starvation • Remaining gas	• Fumes of cleaning material • O_2 starvation • Remaining gas • Residual reactive gaseous decomposition products • Switching dust and adsorbers
Safety precaution	• Ventilation • Measurement of O_2 concentration when entering	• Ventilation • Measurement of O_2 concentration when entering	• Removal of switching dust and adsorbers • Ventilation • Measurement of O_2 concentration when entering • Wear personal protective equipment
Safety equipment and tools	• Suction ventilator or vacuum cleaner • O_2 concentration measuring device	• Suction ventilator or vacuum cleaner • O_2 concentration measuring device	• 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 • Protective goggles

3.6.3 Personal hygiene

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

3.6.4 Handling of contaminated safety equipment/tools

Safety equipment/tools, which have been in contact with switching dust and/or adsorbers shall be considered as contaminated. They shall be collected afterwards and placed in plastic bags. The plastic bags shall be sealed with tape and labelled.

Reusable safety equipment and/or tools shall be washed and neutralised in a water/soda solution with 10% liquid soda and then washed with clean water.

Single use safety equipment and/or tools must be placed in a plastic bag for further disposal according to local regulations. They shall be considered as special waste.

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

3.6.5 Pressurised equipment and tools/measuring devices

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

3.7 Training of personnel

Work on electric power equipment involving SF_6 handling (manufacturing, testing, erection, commissioning, maintenance, service, and dismantling at the end-of-life) must be performed either by trained personnel or under the supervision of trained personnel. For the personnel involved, training is mandatory. 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 SF_6-equipment).
In all cases, the training shall be based on the operating instruction manual from the OEM (e.g. electric power equipment, tools, instruments) and datasheets (e.g. SF_6, cleaning agents).

Training courses shall consist of both theoretical and practical sessions.

Training shall include at least:

- SF_6:
    - Physical/chemical/environmental characteristics of SF_6;
    - Application of SF_6, used in electric power equipment (insulation, arc quenching);
    - Standards;
    - Personnel safety: asphyxiation, contamination; gaseous and solid decomposition products;
    - Environmental impact;
    - Disposal of SF_6 and its gaseous and/or solid decomposition products;

- Electric power equipment:
    - Design and functionality;
    - SF_6-handling on site during erection, commissioning, maintenance, and dismantling at the end-of-life;
    - Benefits of SF_6 technology in electric power equipment;
    - Troubleshooting of electric power equipment utilizing SF_6;

- Handling of SF_6 in electric power equipment:
    - Evacuation of gas compartment;
    - Filling of gas compartment;
    - Recovery, reclaiming and storage of SF_6;
    - Handling of maintenance equipment;
    - Working on open gas compartments;
    - Checking the gas quality.

3.8 Storage and transportation

Storage and transportation of SF_6 shall be performed according to international and local regulations.
The procedures given in the material safety data sheet (MSDS) shall be strictly followed.

3.8.1 Gas categories

With respect to storage and transportation, five gas categories have to be distinguished:

- **New gas or technical grade SF_6**, i.e. SF_6 complying with IEC 60376 [2];
- **SF_6 suited for re-use** in electric power equipment, i.e. SF_6 complying with IEC 60480 [3];
- **SF_6 not suited for reuse** in electric power equipment and **containing neither toxic nor corrosive gaseous decomposition products**, i.e. SF_6 not complying with IEC 60480 [3] and containing CF_4 (carbon tetrafluoride) and/or air and/or nitrogen;
- **SF_6 not suited for re-use** in electric power equipment and **containing toxic gaseous decomposition products**, i.e. SF_6 not complying with IEC 60480 [3] and containing HF (hydrogen fluoride) and SOF_2 (thionyl fluoride);
- **SF_6 not suited for re-use** in electric power equipment and **containing both toxic and corrosive gaseous decomposition products**, i.e. SF_6 not complying with IEC 60480 [3] and containing HF (hydrogen fluoride) and SOF_2 (thionyl fluoride).

3.8.2 Storage of SF_6

Table 8 gives an overview of all possible storage methods on which a storage container may be based.

Table 8: Methods for storage of SF_6

Method	Requirements	Features
Gaseous	Typical pressure lower than 2 MPa. Gas remains in the gaseous state	Requires relatively small recovery pressure differential (typically 100:1) but needs larger storage volumes. Gas cannot be liquefied in cylinders for transportation. Therefore it is limited to small quantities (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 (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. Gas compressed to 5 MPa liquefies by pressure only	Requires recovery differential of 1000:1 but eliminates the need of additional aggregates. Can be used with any storage vessel rated 5 MPa or higher

Characteristics of the gas recovery process are:

- Residual recovery pressure p_{res} [kPa] (residual pressure in equipment down to which the gas can be recovered and compressed to the rated storage pressure p_{st});

- Recovery pressure differential (performance indicator of compressor(s)): p_{st}/p_{res};
- Recovery speed [m^3/min]: Time required recovering a gas volume of 1 m^3 from 500 kPa down to the specified residual recovery pressure p_{res};
- Evacuation speed [m^3/min]: Time required to evacuate a volume of 1 m^3 from atmospheric pressure down to a residual air pressure of 300 Pa;
- Refill speed [kg/min]: Time required filling gas from the storage container at rated storage pressure into the equipment at its rated operating pressure;
- Failsafe operation control (to avoid gas contamination by incorrect handling);
- Filter exchange/handling/disposal facilities.

All the above process speed characteristics assume that there are no losses in the piping between the equipment and reclaimer.

When used SF_6 has to be stored on-site, the storage containers for this purpose should comply with the local pressure vessel regulations and should be labelled in compliance with the regulations given below in section 3.8.4. For practical reasons it is recommended to preferentially use transportable storage containers, wherever possible.

3.8.3 Containers for transportation of SF_6

Each of the five gas categories requires a specific type of container and container labelling, as specified in Table 9.

Table 9: Container types and labelling required for transportation of SF_6

Gas category	Container type	Container labelling
New gas or technical grade SF_6	**Suitable for liquefied gas up to a pressure of 7 MPa.** Note: The filling factor for new gas is up to 1.04 kg/litre. **Recommendation:** Containers should be marked with a green label or the container should be painted green according to DIN EN 1089-3	**Stencilled on container:** UN 1080, sulphur hexafluoride **Danger label 2.2**
SF_6 suited for re-use	**Same type of container as for new or technical grade SF_6.** Note: Due to the inert gas content (N_2, O_2, etc.), the filling factor is smaller than 0.8 kg/litre [note 1]. **Recommendation:** Containers should be specially coloured to avoid confusion between used and new gas (an orange band on the upper third of the cylinder is suggested)	**Stencilled on container:** UN 3163, sulphur hexafluoride, carbon tetrafluoride or air or nitrogen [note 2] **Danger label 2.2**
SF_6 not suited for reuse and containing neither toxic nor corrosive gaseous decomposition products	Same as for SF_6 suited for re-use	**Stencilled on container:** UN 3162, sulphur hexafluoride, carbon tetrafluoride or air or nitrogen [note 2] **Danger label 2.2**
SF_6 not suited for re-use and containing toxic gaseous decomposition products	Same as for SF_6 suited for re-use	**Stencilled on container:** UN 3162, sulphur hexafluoride, hydrogen fluoride, thionyl fluoride [note 2] **Danger label 2.3**
SF_6 not suited for re-use and containing both toxic and corrosive gaseous decomposition products	**Special containers approved for storing and transportation of corrosive gases** (such as hydrofluoric acid HCl) with a corrosion-proof valve and adapter	**Stencilled on container:** UN 3308, sulphur hexafluoride, hydrogen fluoride, thionyl fluoride **Danger labels 2.3 + 8**

Note 1: The filling factor is the weight of SF_6 contained in the container divided by the container volume and is usually specified in kg/litre
Note 2: Only the two most abundant contaminants have to be specified

3.8.4 Modes for shipment of SF_6

Electric power equipment containing SF_6 and/or SF_6 containers are shipped by:

- Road (ADR)
- Rail (RID);
- Ship (IMDG code);
- Air (IATA - DGR);

Internationally accepted regulations for shipment of SF_6 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 regulations for road, rail, ship and air transport are summarised in Table 10.

Table 10: International regulations for shipment of SF_6 by road (ADR), rail (RID), ship (IMDG code), and air (IATA – DGR).

Item	**New gas or technical grade SF_6**	**SF_6 suited for re-use**	**SF_6 not suited for reuse and containing neither toxic nor corrosive gaseous decomposition products**	**SF_6 not suited for re-use and containing toxic gaseous decomposition products**	**SF_6 not suited for re-use and containing both toxic and corrosive gaseous decomposition products**
UN Number	UN 1080 liquefied gas	UN 3163 liquefied gas	UN 3163 liquefied gas	3162 liquefied toxic gas	UN 3308 liquefied toxic and corrosive gas
Class	2A	2A	2A	2T	2TC
Danger label	2.2	2.2	2.2	2.3	2.3 + 8
Final classification	UN 1080 liquefied gas, n.o.s. 2.2	UN 3163 liquefied gas, n.o.s. 2.2	UN 3163 liquefied gas, n.o.s. 2.2	UN 3162 liquefied gas, n.o.s. 2.3	UN 3308 liquefied gas, n.o.s. 2.3 + 8
Transport document	UN 1080 liquefied gas, n.o.s (sulphur hexafluoride) 2.2	UN 3163 liquefied gas, n.o.s. (sulphur hexafluoride and air or nitrogen or carbon tetrafluoride) 2.2	UN 3163 liquefied gas, n.o.s. (sulphur hexafluoride and air or nitrogen or carbon tetrafluoride) 2.2	UN 3162 liquefied gas, toxic, n.o.s. (sulphur hexafluoride and hydrogen fluoride and thionyl fluoride 2.3	UN 3308 liquefied gas, toxic, corrosive, n.o.s. (sulphur hexafluoride and hydrogen fluoride and thionyl fluoride 2.3 + 8
Note: Any contamination of packaging exclusively dedicated to new SF_6 shall be avoided					

3.9 Responsibilities

The owner of the SF_6 electric power equipment is responsible for the proper use, transportation, and disposal of both the equipment and the gas. He is also responsible for record-keeping regarding SF_6 banked in equipment and/or stored in cylinders as well as emission rates on a yearly basis. This is supported by the equipment manufacturer and the gas producer with basic information.

3.10 References

3.10.1 Local regulations

List here the national/local regulations to comply with when handling SF_6 in electric power equipment.

3.10.2 Standards

[1] IEC Standard 61276-200, 1st edition 2003, "A.C. metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV".

[2] IEC Standard 60376, 1st edition 1971 – and new FDIS under circulation, "Specification and acceptance of new sulphur hexafluoride".

[3] IEC Standard 60480, 2nd edition 2004, "Guide to the checking and treatment of sulphur hexafluoride (SF_6) taken from electrical equipment and specification for its re-use".

[4] IEC Standard 61276-203, 1st edition 2003, "Gas-insulated metal-enclosed switchgear for rated voltages above 52 kV".

[5] IEC Standard 60694, 2.2 edition 2002 and new CDV 62271-1 under circulation "Common specifications for high-voltage switchgear and controlgear standards".

[6] IEC Technical Report 61634, 1st edition 1995 "High-voltage switchgear and controlgear – Use and handling of sulphur hexafluoride (SF_6) in high-voltage switchgear and controlgear".

[7] IEC Standard 61640, 1st edition 1998 "Rigid high-voltage, gas-insulated transmission lines for rated voltage of 72,5 kV and above"

[8] ISO Standard 14040, 1997 "Environmental management – Life cycle assessment – Principles and framework"

3.10.3 Datasheets from suppliers

List here the datasheets from the SF_6 supplier.
List here the datasheet of the electric power equipment from the Original Equipment Manufacturer.

3.10.4 Others

[9] Owens, J. G., "Calculation of the Global Warming Potential fur sulfur hexafluoride using the updated Atmospheric Lifetime from Moore, et al.", Gaseous dielectrics IX, pp. 91 – 92, 2001

[10] IPCC (Intergovernmental Panel on Climate Change), Third Assessment Report: Climate Change 2001", 2001

[11] The CAPIEL Cradle-to-Grave Inventory Methodology for SF_6 Insulated electrical High Voltage Switchgear in Europe, EPA Conference November 2002

[12] CIGRE TF 23-02.01, "Handling of SF_6 and its decomposition products in Gas Insulated Switchgears (GIS)", ELECTRA, 136 and 137, 1991

[13] CIGRE TF B3-02.01, "SF_6 Recycling Guide. Re-use of SF_6 gas in electrical power equipment and final disposal (Revision 2003)", CIGRE Brochure 234, 2003

[14] Template for Voluntary agreement on the use of SF_6 and on measures for SF_6 emission reduction in the national, regional electric industry. CIGRE WG B3-02, 2003

[15] Project Group ABB, PreussenElektra, RWE, Siemens, and Solvay, Electricity supply using SF_6 technology, summary given in: B. Zahn and E. Ruess, Economical and ecological system comparison for the electricity supply of an urban area, CIGRE SC23.99 (COLL) IWD, Zurich, 1999

[16] Solvay Management Support: SF_6-GIS-Technologie in der Energieverteilung – Mittelspannung. Life Cycle Assessment study commissioned by ABB, Areva T&D, EnBW Regional, e.on Hanse, RWE, Siemens, and Solvay Fluor und Derivate. Solvay: Hannover/Germany, 2003 (in German, abstract and summary available in English)

4 PROCEDURE DESCRIPTION MODULES

This chapter cover the different phases where SF_6 shall be handled on site, that is:

- Commissioning or re-commissioning of SF_6 compartments;
- Topping-up or re-filling of SF_6 compartments to the nominal pressure/density;
- Checking the SF_6 quality in gas compartments;
- Sampling and transportation of SF_6
- Recovery and reclaiming of SF_6 at maintenance or repair
- Recovery and reclaiming of SF_6 at the end-of-life disposal when the electric power equipment is dismantled.

4.1 Commissioning or re-commissioning of SF_6 compartments

This module applies to compartments of controlled and/or closed pressure systems that currently contain a gas different from SF_6 (typically air or N_2) at ambient pressure or slightly overpressure (typically 100 to 150 kPa).

This module does not apply to compartments of controlled and closed pressure systems that currently contain SF_6 at a pressure above the atmosphere (typically 120 to 150 kPa). They shall be topped-up as described in paragraph 4.2.

This module does not apply to leaking compartments of controlled and/or closed pressure systems to assure continuity of service. They shall be re-filled as described in paragraph 4.3.

Unless otherwise specified by the equipment manufacturer in the Operating Instruction Manual, the following detailed sequence of operations for air/N_2 evacuation and SF_6 filling in each compartment shall be performed according to Figure 1. Additional details are given in Table 11.

Figure 1: Diagram of the operations for commissioning or re-commissioning of SF_6 compartments.

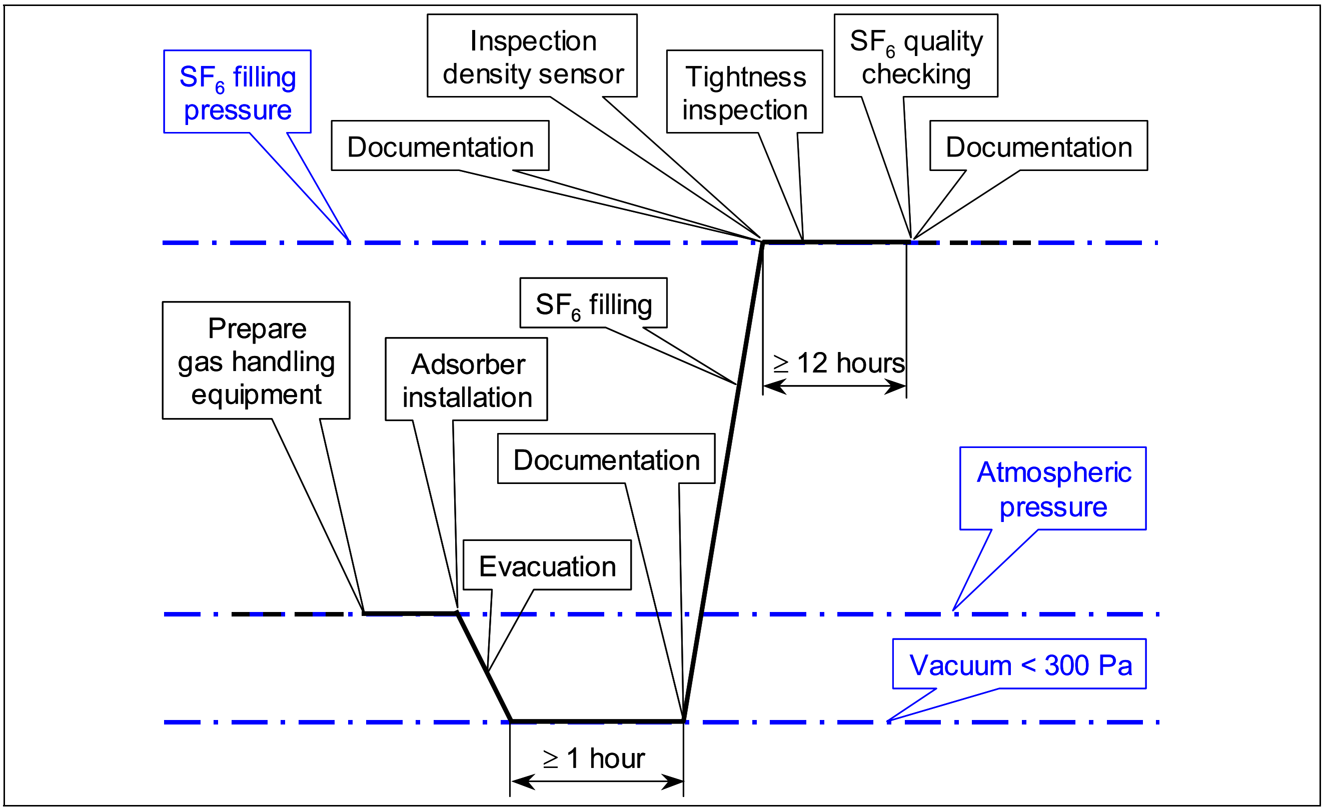


Table 11: Operational description for commissioning or re-commissioning of SF_6 compartments.

Step		Procedure
1	Prepare gas handling equipment	Check that the gas reclaimer is working properly and the gas connections are clean and dry to avoid contamination. Check the validity of the calibration of instruments subject to calibration.
2	Adsorber installation	Quickly insert the adsorbers in the compartment. Start evacuation immediately afterwards.
3	Evacuation	Connect the vacuum pump and leave it running until a vacuum level smaller than 300 Pa for at least 1 hour is reached in the gas compartment [note 1].
4	Residual air and/or moisture content	Detach the vacuum pump and read the pressure gauge. The vacuum level shall be smaller than 400 Pa.
5	Documentation	Record at least the serial number of the gas compartment, the vacuum level of the residual air content, ambient temperature and date for further reference.
6	Filling with SF_6	Connect the SF_6 container and fill the compartment until the SF_6 rated filling pressure is reached. Use a safety valve and a calibrated gauge to avoid overfilling [notes 2 and 3].
7	Documentation	Record at least the serial number of the gas compartment, the final filling pressure, ambient temperature and date for further reference.
8	Pressure/density sensor inspection	Check the functionality of the pressure/density sensor. The operation can be performed during the filling operation.
9	Tightness inspection	Check the tightness of at least all permanent connections made on site.
10	SF_6 quality checking	Wait at least 12 hours after the filling operation and then measure the moisture content and the SF_6 content of the gas in the compartment (see paragraph 4.2 for details).
11	Documentation	Record at least the serial number of the gas compartment, the functionality of the pressure/density sensor, the moisture content, the SF_6 content, ambient temperature and date for further reference.

Note 1: The residual pressure of air in the gas compartment shall remain smaller than 300 Pa for at least 1 hour, according to Appendix 1.

Note 2: SF_6 gas to be introduced into the gas compartment shall comply with one of the following gas categories as defined in paragraph 3.5:

- New gas or technical grade SF_6;
- Suited for the complete range of re-use pressures;
- Suited for the low range of re-use pressures only in the case that the SF_6 rated filling pressure of the equipment does not exceed the re-use limit, i.e. 200 kPa.

Note 3: No gas check is required if the gas comes from the supplier in sealed cylinders or containers. In all other cases, the gas quality shall be checked prior to the filling operation. The gas quality check shall comprise moisture content, SF_6 percentage, and residual acidity content.

4.2 Topping-up of SF_6 pre-filled compartments to the nominal pressure/density

This module applies to compartments of controlled and/or closed pressure systems that contain SF_6 at above atmospheric pressure (typically 120 to 150 kPa). This is typically done for the purpose of shipping pre-filled new equipment.

This module does not apply to compartments of controlled and/or closed pressure systems that currently contain a gas different from SF_6 (typically air or N_2) at ambient pressure or slightly overpressure (typically 100 to 150 kPa). These shall be commissioned or re-commissioned as described in paragraph 4.1.

This module does not apply to leaking compartments of controlled and/or closed pressure systems to assure continuity of service. These shall be re-filled as described in paragraph 4.3.

Unless otherwise specified by the equipment manufacturer in the Operating Instruction Manual, the following detailed sequence of operations for SF_6 topping-up in each pre-filled compartment shall be performed according to Figure 2. Additional details are given in Table 12.

Figure 2: Diagram of the operations for topping-up of SF_6 pre-filled compartments to the nominal pressure/density.

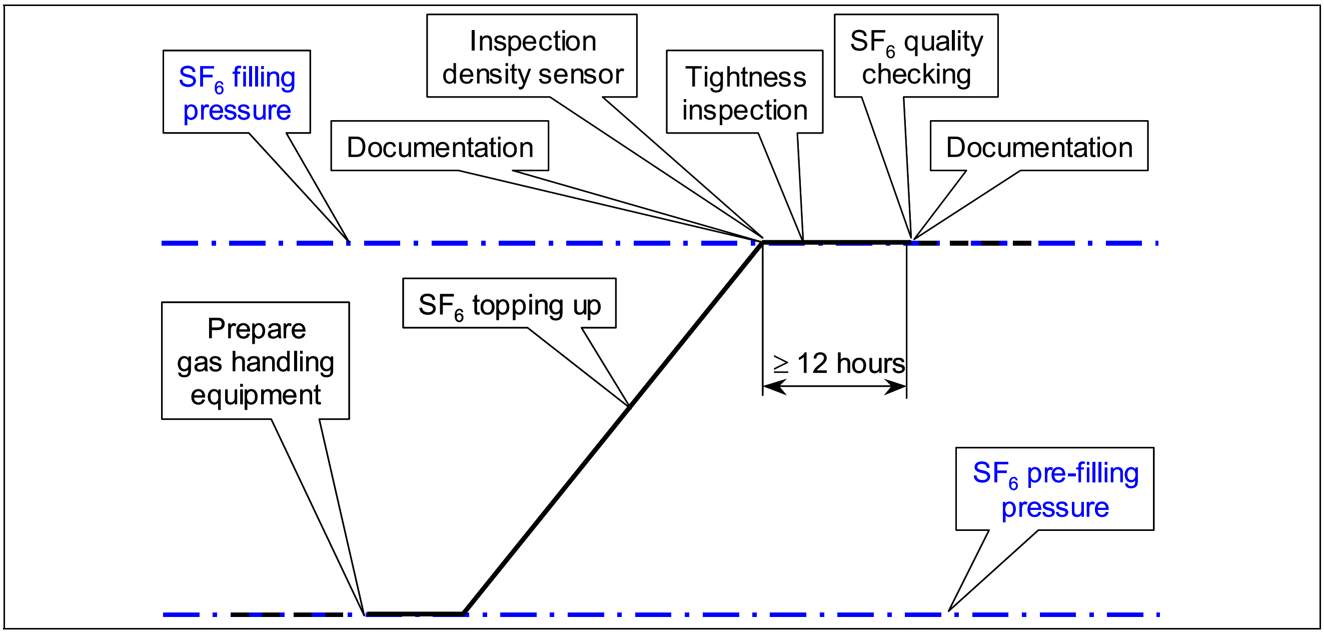


Table 12: Operational description for topping-up of SF_6 pre-filled compartments to the nominal pressure/density.

Step		Procedure
1	Prepare gas handling equipment	Check that the gas reclaimer is working properly and the gas connections are clean and dry to avoid contamination. Check the validity of the calibration of instruments subject to calibration.
2	Topping-up with SF_6	Connect the SF_6 container and fill the compartment until the SF_6 rated filling pressure is reached. Use a safety valve and a calibrated gauge to avoid overfilling [notes 1 and 2].
3	Documentation	Record at least the serial number of the gas compartment, the final filling pressure, ambient temperature and date for further reference.
4	Pressure/density sensor inspection	Check the functionality of the pressure/density sensor. The operation can be performed during the filling operation.
5	Tightness inspection	Check the tightness of at least all permanent connections made on site.
6	SF_6 quality checking	Wait at least 12 hours after the filling operation and then measure the moisture content and the SF_6 content of the gas in the compartment (see paragraph 4.2 for details).
7	Documentation	Record at least the serial number of the gas compartment, the functionality of the pressure/density sensor, the moisture content, the SF_6 content, ambient temperature and date for further reference.

Note 1: SF_6 gas to be introduced into the gas compartment shall comply with one of the following gas categories as defined in paragraph 3.5:

- New gas or technical grade SF_6;
- Suited for the complete range of re-use pressures;
- Suited for the low range of re-use pressures only in the case that the SF_6 rated filling pressure of the equipment does not exceed the re-use limit, i.e. 200 kPa.

Note 2: No gas check is required if the gas comes from the supplier in sealed cylinders or containers. In all other cases, the gas quality shall be checked prior to the filling operation. The gas quality check shall comprise moisture content, SF_6 percentage, and residual acidity content.

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

This module applies to leaking compartments (usually indicated by the first alarm/indication of the pressure/density monitor) of controlled and/or closed pressure systems to assure continuity of service. In this case, appropriate corrective measures to locate and eliminate the leak shall be immediately arranged.

This module does not apply to leaking energised compartments. The Operating Instruction Manual from the equipment manufacturer shall be strictly observed.

This module does not apply to compartments of controlled and closed pressure systems that currently contain a gas different from SF_6 (typically air or N_2) at ambient pressure or slightly overpressure (typically 100 to 150 kPa). These shall be commissioned or re-commissioned as described in paragraph 4.1.

This module does not apply to compartments of controlled and/or closed pressure systems that contain SF_6 at a pressure above the atmosphere (typically 120 to 150 kPa). These shall be topped-up as described in paragraph 4.2.

Unless otherwise specified by the equipment manufacturer in the Operating Instruction Manual, the following detailed sequence of operations for gas re-filling in each compartment shall be performed according to Figure 3. Additional details are given in Table 13.

Figure 3: Diagram of the operations for SF_6 re-filling of SF_6 to the nominal pressure/density.

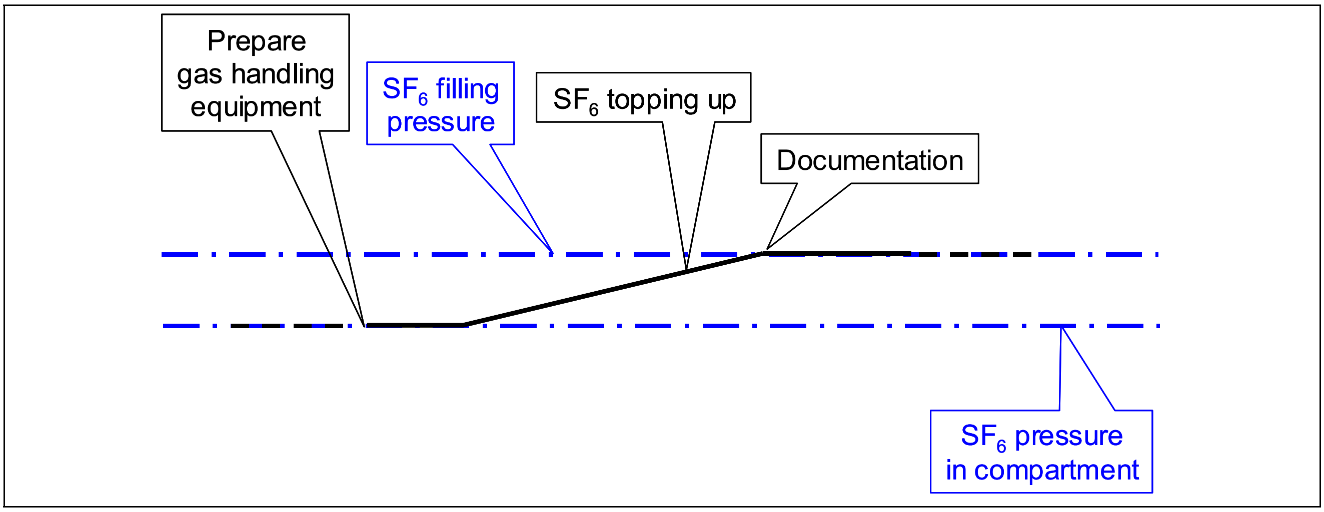


Table 13: Operational description for re-filling of SF_6 to the nominal pressure/density.

Step		Procedure
1	Prepare gas handling equipment	Check that the gas connections are clean and dry to avoid contamination. Check the validity of the calibration of instruments subject to calibration.
2	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 and a calibrated gauge to avoid overfilling [notes 1, 2, and 3].
3	Documentation	Record at least the serial number of the gas compartment, the final filling pressure, ambient temperature and date for further reference.

Note 1: SF_6 gas to be introduced into the gas compartment shall comply with one of the following gas categories as defined in paragraph 3.5:

- New gas or technical grade SF_6;
- Suited for the complete range of re-use pressures;
- Suited for the low range of re-use pressures only in the case that the SF_6 rated filling pressure of the equipment does not exceed the re-use limit, i.e. 200 kPa.

Note 2: No gas check is required if the gas comes from the supplier in sealed cylinders or containers. In all other cases, the gas quality shall be checked prior to the filling operation. The gas quality check shall comprise moisture content, SF_6 percentage, and residual acidity content.

Note 3: As the amount of gas used for re-filling is very small in comparison to the amount of gas in the related compartment, it is not necessary to perform a SF_6 gas quality check after the re-filling operation.

4.4 Checking the SF_6 quality in gas compartments on-site

The measurement of the SF_6 quality is usually done on-site, using portable equipment. Off-site analysis may exceptionally be performed to cross-check unsatisfactory on-site results, by sampling the gas and sending it to a qualified chemical laboratory.
Depending on the category of the SF_6 contained in the gas compartment or container, different physical characteristics (e.g. moisture content, SF_6 content, residual equivalent acidity) shall be checked. Minimum requirements are given in Table 14.

Table 14: Minimum SF_6 characteristics to check, depending on the gas category

SF_6 category	SF_6 characteristics
Non arced gas	Moisture, SF_6 content
Normally arced gas	Moisture, SF_6 content, residual acidity content
Heavily arced gas	Moisture, SF_6 content, residual acidity content

The residual acidity content shall be checked first to prevent damage of other instruments, if normally or heavily arced gas is expected.

4.4.1 Measurement of the moisture content/dew point of SF_6 on-site

This module applies to SF_6 filled compartments of controlled and/or closed pressure systems or SF_6 filled containers to check the moisture content/dew point of the gas on-site.

Unless otherwise specified by the equipment manufacturer in the Operating Instruction Manual, the following detailed sequence of operations for an on-site SF_6 moisture check shall be performed according to Figure 4. Additional details are given in Table 15.

Characteristics of portable dew point meters are given in paragraph 5.3.1.1.

Figure 4: Diagram of the operations for the measurement of the moisture content/dew point of SF_6 on-site.

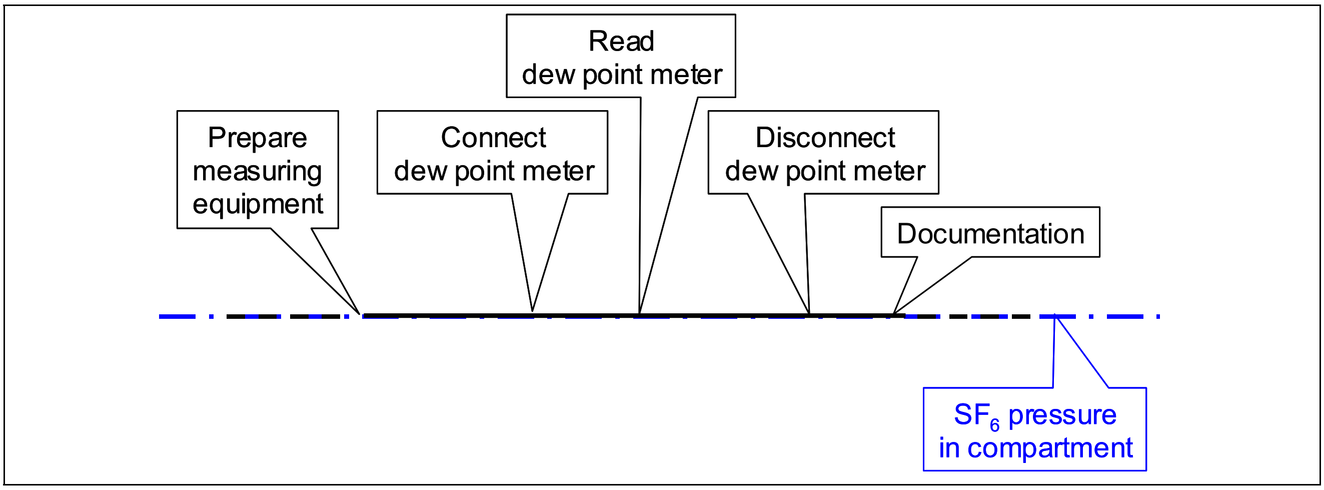


Table 15: Operational description for the measurement of the moisture content/dew point of SF_6 on-site.

Step		Procedure
1	Prepare measuring equipment	Check that the dew point meter is working properly; and the gas connections are clean and dry 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 dew point meter	Attach the dew point meter. Make tight connections and establish gas flow.
3	Read the dew point meter	Refer to the Operating Instruction Manual provided by the instrument manufacturer.
4	Disconnect the dew point meter	Stop the gas flow and detach the dew point meter.
5	Documentation	Record at least the serial number of the gas compartment, the reading and the date for further reference.

4.4.2 Measurement of the SF_6 content/quantity of inert gases on-site

This module applies to SF_6 filled compartments of controlled and/or closed pressure systems or SF_6 filled containers to check the SF_6 content/quantity of inert gases on-site.

Unless otherwise specified by the equipment manufacturer in the Operating Instruction Manual, the following detailed sequence of operations for an on-site measurement of the SF_6 content/quantity of inert gases shall be performed according to Figure 5. Additional details are given in Table 16.

Characteristics of portable SF_6 content measuring devices are given in paragraph 5.3.1.2.

Figure 5: Diagram of the operations for the measurement of the SF_6 content/ quantity of inert gases on-site.

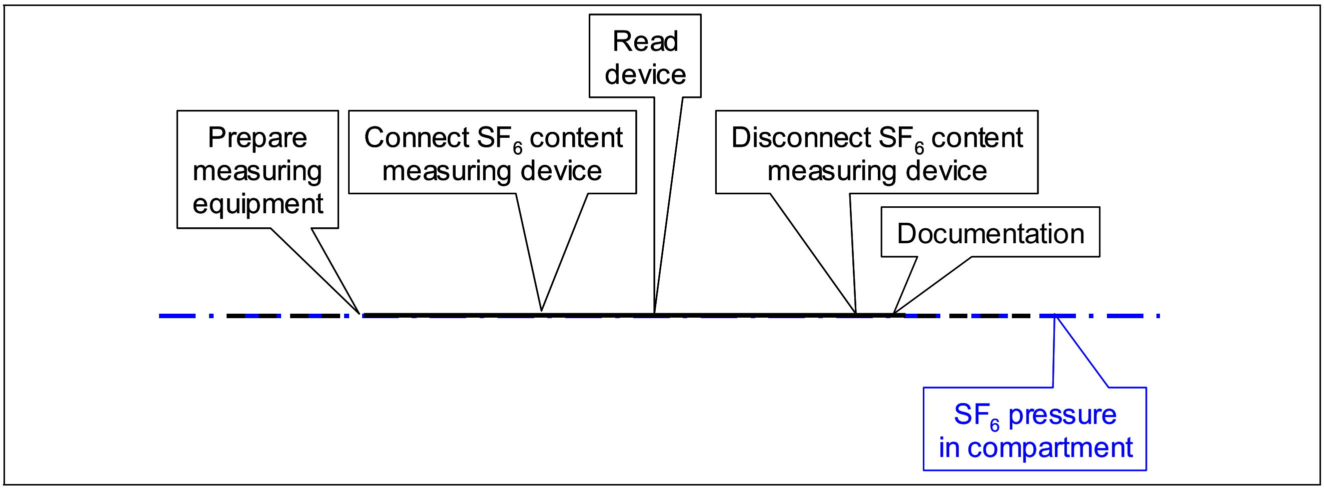


Table 16: Operational description for the measurement of the SF_6 content/quantity of inert gases on-site.

Step		Procedure
1	Prepare measuring equipment	Check that the SF_6 content measuring device is working properly and the gas connections are clean and dry 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 SF_6 content measuring device	Attach the SF_6 content measuring device. Make tight connections and establish the gas flow.
3	Read the SF_6 content	Refer to the Operating Instruction Manual provided by the instrument manufacturer.
4	Disconnect the SF_6 content measuring device	Stop the gas flow and detach the SF_6 content measuring device.
5	Documentation	Record at least the serial number of the gas compartment, the reading and the date for further reference.

4.4.3 Measurement of the residual quantity of reactive gaseous decomposition products/residual acidity content on-site

This module applies to SF_6 filled compartments of controlled and/or closed pressure systems or SF_6 filled containers to check the residual quantity of reactive gaseous decomposition products/residual acidity content on-site.

Unless otherwise specified by the equipment manufacturer in the Operating Instruction Manual, the following detailed sequence of operations for an on-site measurement of the residual quantity of reactive gaseous decomposition products/residual acidity content shall be performed according to Figure 6. Additional details are given in Table 17.

Portable analysers of reactive gaseous decomposition products are described in paragraph 5.3.1.3.

Figure 6: Diagram of the operations for the measurement of the residual quantity of reactive gaseous decomposition products/residual acidity content on-site.

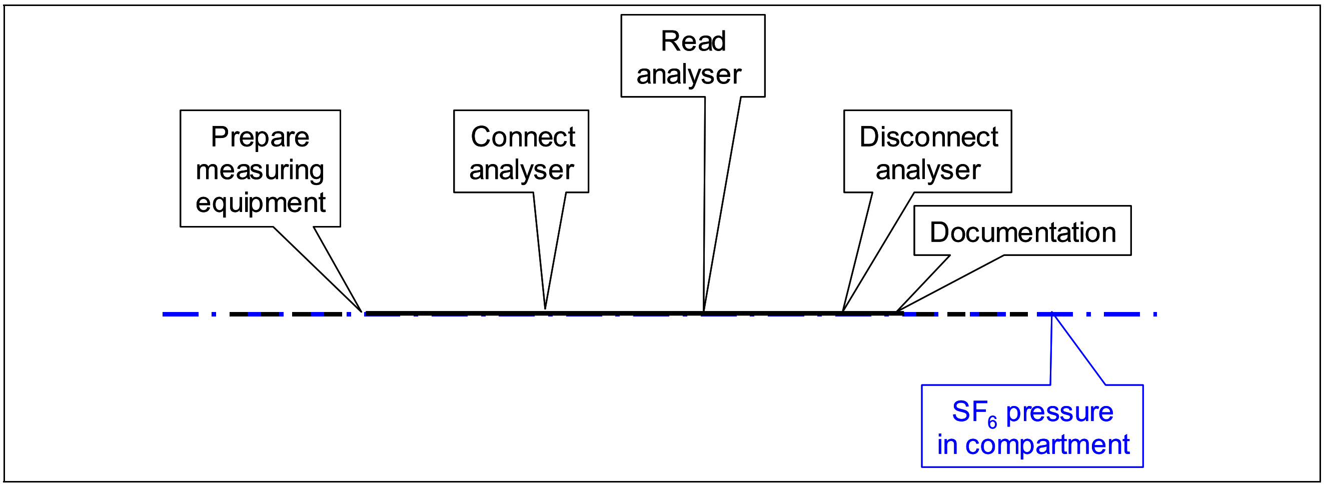


Table 17: Operational description for the measurement of the residual quantity of reactive gaseous decomposition products/residual acidity content on-site.

Step		Procedure
1	Prepare measuring equipment	Check that the analyser of reactive gaseous decomposition products is working properly and the gas connections are clean and dry 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 analyser of reactive gaseous decomposition products	Attach the analyser of reactive gaseous decomposition products [note]. Make tight connections and establish gas flow.
3	Read the analyser of reactive gaseous decomposition products	Refer to the Operating Instruction Manual provided by the instrument manufacturer.
4	Documentation	Record at least the serial number of the gas compartment, the reading and the date for further reference.
5	Disconnect the analyser of reactive gaseous decomposition products	Stop the gas flow and detach the analyser of reactive gaseous decomposition products.

4.5 Sampling and shipment of SF_6 for off-site analysis

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

Unless otherwise specified by the equipment manufacturer in the Operating Instruction Manual, the following detailed sequence of operations for gas sampling and shipment shall be performed according to Figure 7. Additional details are given in Table 18.

Characteristics of cylinders for gas samples are described in paragraph 5.4.

Figure 7: Diagram of the operations for gas sampling and shipment

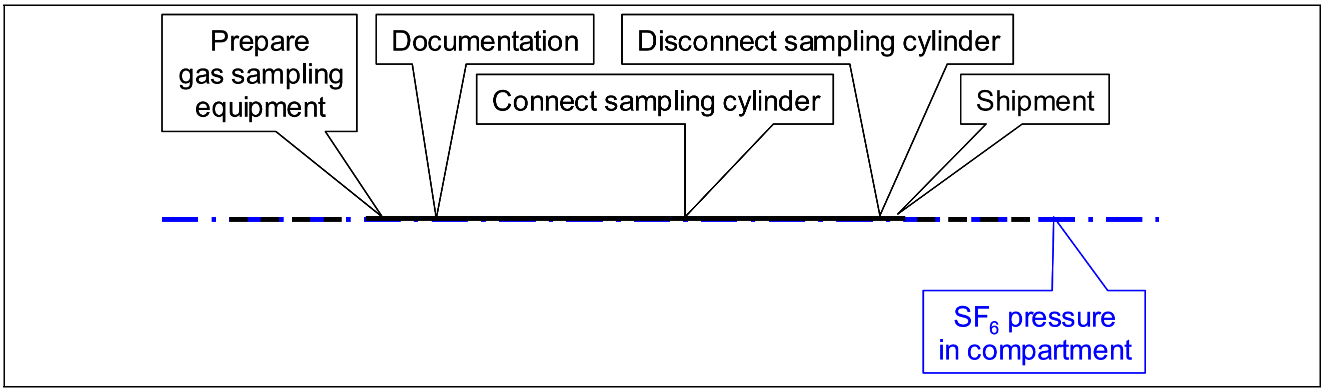


Table 18: Operational description for gas sampling and shipment.

Step		Procedure
1	Prepare gas sampling equipment	Evacuate the sampling cylinder [note]. Check that the gas connections are clean and dry to avoid contamination of the sample and use short connections to minimise SF_6 release.
2	Documentation	Tag the sampling cylinder with at least the following information: the serial number of the gas compartment, date, pressure, and ambient temperature.
3	Connect the sampling cylinder	Attach the sampling cylinder. Make tight connections and establish gas flow.
4	Disconnect the sampling cylinder	Stop gas flow and detach the sampling cylinder.
5	Shipment	Transportation to the laboratory shall be done in accordance to international and local regulations, as described in paragraph 3.8.3.
Note: Stainless steel cylinders with a volume smaller than 1 litre shall be used		

4.6 Recovery and reclaiming of non-arced and/or normally arced SF_6 from compartments of controlled and/or closed pressure systems

This module applies to compartments of controlled and/or closed pressure systems that contain non-arced or normally arced SF_6 to be recovered for maintenance or end-of-life disposal when the equipment is dismantled.

This module does not apply to compartments of controlled and/or closed pressure systems that contain heavily arced SF_6 to be recovered and reclaimed. These shall be handled as described in paragraph 4.7.

This module does not apply to compartments of sealed pressure system. These shall be handled as described in paragraph 4.8.2.

Unless otherwise specified by the equipment manufacturer in the Operating Instruction Manual, the following detailed sequence of operations for recovery of non-arced and normally arced gas from each compartment shall be performed according to Figure 8. Additional details are given in Table 18.

The five safety rules given in paragraph 3.6 shall be strictly followed.

Figure 8: Diagram of the operations for recovery and reclaiming of non-arced and/or normally arced SF_6 from compartments of controlled and/or closed pressure systems.

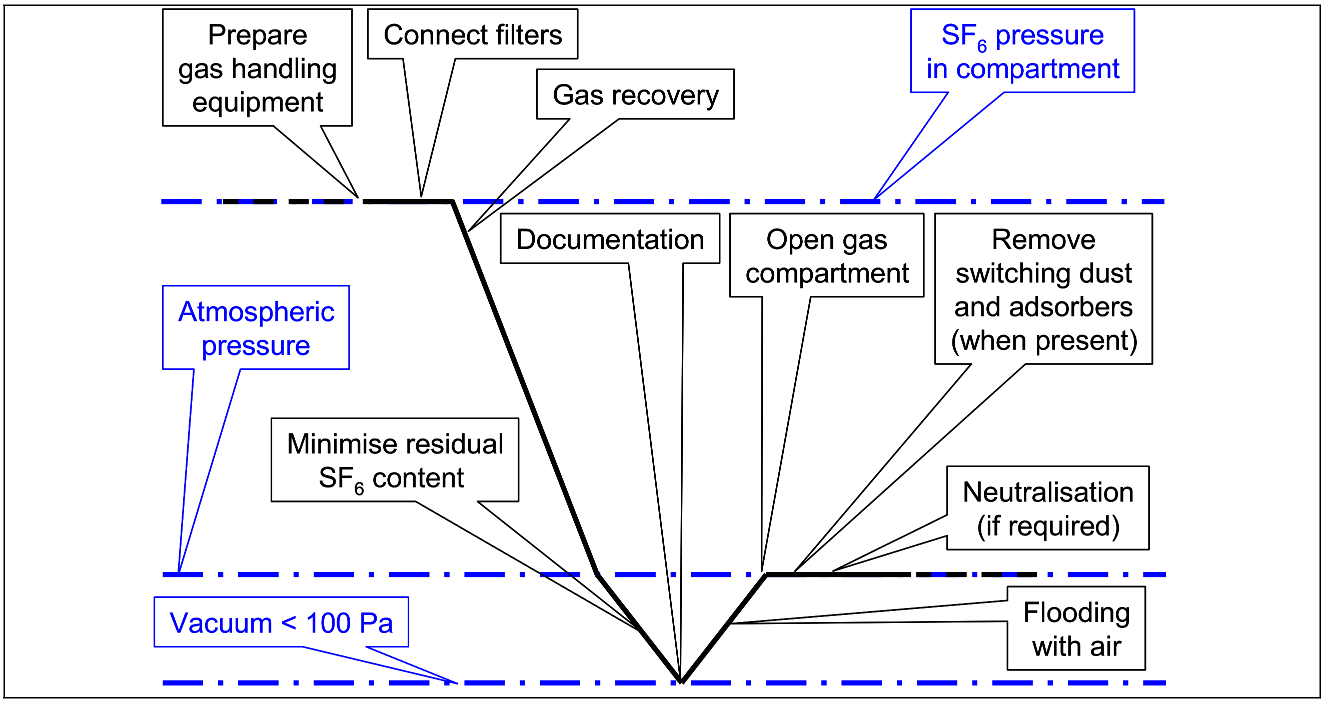


Table 19: Operational description for recovery and reclaiming of non-arced or normally arced SF_6 from compartments of controlled and/or closed pressure systems.

Step		Procedure
1	Prepare gas handling equipment	Check that the gas reclaimer is properly working, the filters and pre-filters are still active, and the gas connections are clean and dry to avoid contamination. Check the validity of the calibration of instruments subject to calibration.
2	Connect filters	Connect the pre-filter between the gas compartment and the compressor and the filter between the compressor and the storage container.
3	Gas recovery	Connect the SF_6 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 [note 1].
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 smaller than 100 Pa is reached [note 2] [note 3].
5	Documentation	Record at least the serial number of the gas compartment, the reading and the date for further reference.
6	Flooding with air	Detach the compressor and let the air enter slowly into the gas compartment.
7	Open the gas compartment	Carefully open the gas compartment. Apply safety rules according to paragraph 3.6.
8	Remove switching dust and adsorbers when present	Immediately use vacuum cleaner or wipe with a clean lint free rag to collect the dust, if present. Place adsorbers in a plastic bag. Seal the plastic bag with tape and tag it.
9	Neutralisation, if required	If switching dust was collected, use 10% soda solution or equivalent to wash and neutralise all parts and then wash with clean water.

Note 1: In the case of liquid storage the weight of the storage container shall be controlled in order to avoid overfilling. The filling factor is smaller than 0.8 kg/litre for safety reasons.

Note 2: State-of-the-art handling equipment is capable of reaching a residual pressure of SF_6 in the gas compartment lower than 100 Pa, according to 5.1.4. For different SF_6 residual pressures refer to Appendix 1.

Note 3: A SF_6 residual pressure lower than 2 kPa (instead of 100 Pa) applies to MV equipment, according to Appendix 1

4.7 Recovery and reclaiming of heavily arced SF_6 from compartments of controlled and/or closed pressure systems

This module applies to compartments of controlled and/or closed pressure systems that contain heavily arced SF_6 to be recovered for maintenance or at the end-of-life disposal when the equipment is dismantled.

This module does not apply to compartments of controlled and/or closed pressure systems that contain non-arced or normally arced SF_6 to be recovered and reclaimed. These shall be handled as described in paragraph 4.6.

This module does not apply to compartments of sealed pressure systems. These shall be handled as described in paragraph 4.8.2.

Unless otherwise specified by the equipment manufacturer in the Operating Instruction Manual, the following detailed sequence of operations for recovery of heavily arced gas from each compartment shall be performed according to Figure 9. Additional details are given in Table 20.

The five safety rules given in paragraph 3.6 shall be strictly followed.

Figure 9: Diagram of the operations for recovering and reclaiming of heavily arced SF_6 from compartments of controlled and/or closed pressure systems.

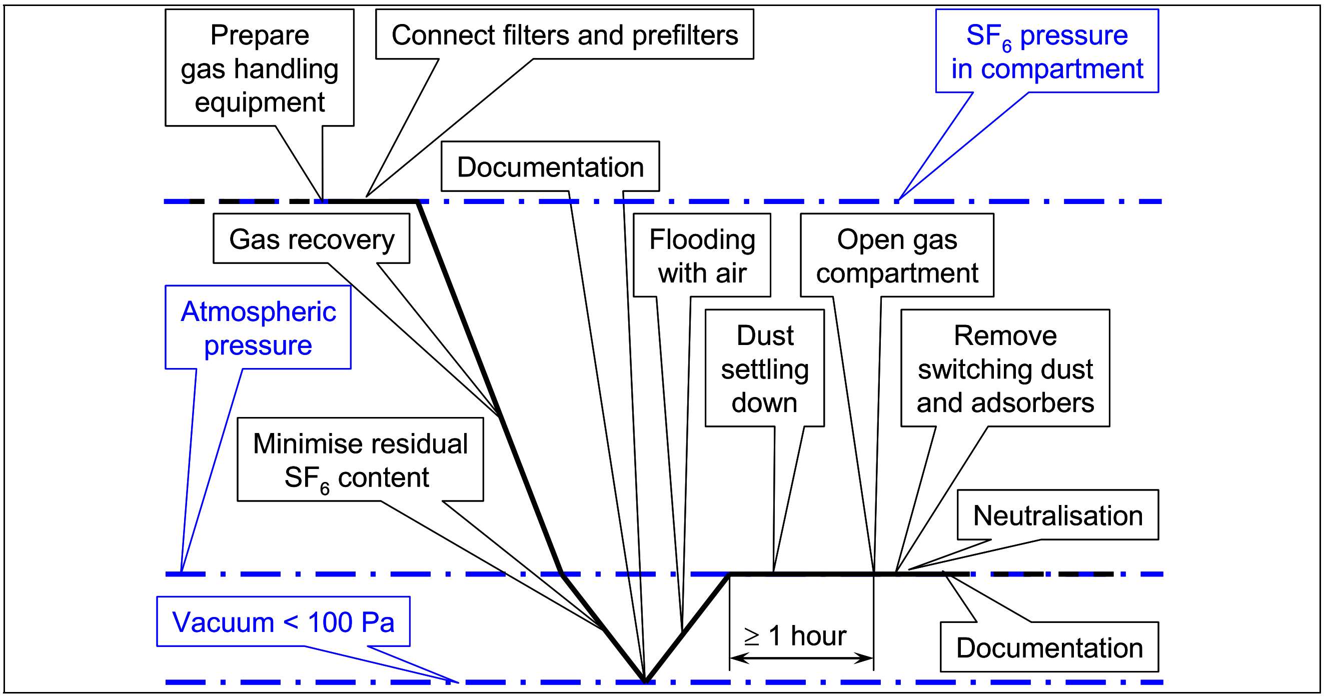


Table 20: Operational description for recovery and reclaiming of heavily arced SF_6 from compartments of controlled and/or closed pressure systems.

Step		Procedure
1	Prepare gas handling equipment	Check that the gas reclaimer is properly working, the filters and pre-filters are still active and the gas connections are clean and dry to avoid contamination. Check the validity of the calibration of instruments subject to calibration.
2	Connect filters	Connect the pre-filter between the gas compartment and the compressor and the filter between the compressor and the storage cylinder.
3	Connect additional pre-filter	Connect an additional pre-filter at the inlet of the gas reclaimer.
4	Gas recovery	Connect the SF_6 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 [note 1].
5	Minimise residual SF_6 content	Connect the auxiliary compressor stage when the SF_6 residual pressure in the compartment approaches 100 kPa and leave it running until a pressure smaller than 100 Pa is reached [note 2] [note 3].
6	Documentation	Record at least the serial number of the gas compartment, the reading and the date for further reference.
7	Flooding with air	Detach the compressor and let the air enter slowly into the gas compartment.
8	Settling down of switching dust	Wait at least for 1 hour to give enough time the remaining switching dust to settle down in the gas compartment.
9	Open the gas compartment	Carefully open the gas compartment. Apply safety rules according to paragraph 3.6.
10	Remove switching dust, adsorbers and removable parts	Immediately use a vacuum cleaner to collect the dust. Place adsorbers and removable parts in plastic bags. Seal plastic bags with tape and tag them.
11	Neutralisation	Use 10% soda solution or equivalent to wash and neutralise all parts and then wash with clean water.
12	Documentation	Record all relevant information concerning the internal fault. Include some pictures.
Note 1:	In the case of liquid storage the weight of the storage container shall be controlled in order to avoid overfilling. The filling factor is smaller than 0.8 kg/litre for safety reasons.	
Note 2:	State-of-the-art handling equipment is capable of reaching a residual pressure of SF_6 in the gas compartment lower than 100 Pa, according to 5.1.4. For different SF_6 residual pressures refer to Appendix 1.	
Note 3:	A SF_6 residual pressure lower than 2 kPa (instead of 100 Pa) applies to MV equipment, according to Appendix 1	

4.8 Recovery and reclaiming of SF_6 at the end-of-life disposal when the electric power equipment is dismantled

This chapter covers the different phases where SF_6 shall be handled during the end-of-life disposal when dismantling is chosen for the end-of-life of electric power equipment.

End-of-life disposal/dismantling is performed under the user's responsibility and supported by the manufacturer. Third parties, such as qualified service companies, may also carry out end-of-life disposal/dismantling.

When the equipment is dismantled its material components will typically be metal materials such as aluminium, copper, aluminium casting components, low voltage components, hydraulic fluid and grease. SF_6 gas and its gaseous and solid decomposition products. Almost 90% of all materials can be re-used. The materials have to be sorted before delivering to the waste collector.

Electrical switchgear dismantling and related treatment of polluted gas, enclosures, powders, adsorbers and effluents shall be conducted with due regard to personnel and environment safety, as described in paragraph 3.6 and IEC 61634 [6].

In particular, SF_6 gas shall be recovered, reclaimed, and recycled using an appropriate procedure before any other dismantling operations. Then, any contaminants in the remaining part of the switchgear shall be removed, if necessary.

After treatment, the equipment can be recycled as normal electrical waste.

4.8.1 Closed and controlled pressure systems

For this equipment, the gas recovery takes place either on-site or off-site and corresponding procedures are given in paragraphs 4.6 (Non-arced or normally arced SF_6) and 4.7 (Heavily arced SF_6).

4.8.2 Sealed pressure systems

Generally, sealed pressure systems are collected for destruction before removal of SF_6, this operation being conducted by service companies. These companies must implement the necessary handling and storage means to avoid any shocks that may crack or break the enclosure, in particular resin-based enclosures. Experience shows that the risk of the SF_6 gas being dispersed in the environment during handling and transportation is extremely slight, if the manufacturer's transportation instructions are followed.

The devices to be dismantled may come from a number of places. For this reason, the residual quantity of gaseous and solid decomposition products sometimes cannot be determined prior to opening of the equipment. In these cases, the gas shall be considered as heavily arced and the procedure of paragraph 4.7 shall be applied. When it can be demonstrated that the SF_6 is non-arced or normally arced, e.g. SF_6 not exposed to current breaking and/or internal arc, then the procedure of paragraph 4.6 can be applied.

When sealed pressure systems are fitted with connecting facilities, dedicated tools according to manufacturer instructions should preferably be used for the gas recovery. If not, then tight drilling systems as described in paragraph **Erreur ! Source du renvoi introuvable.** should be used.

Unless otherwise specified by the equipment manufacturer in the Operating Instruction Manual, the following detailed sequence of operations for SF_6 handling at the end-of-life disposal, when the sealed pressure systems is dismantled, shall be performed according to Figure 10. Additional details are given in Table 21.

The five safety rules given in paragraph 3.6 shall be strictly followed.

Figure 10: Diagram of the operations for recovery and reclaiming of SF_6 at the end-of-life disposal when the sealed pressure system is dismantled.

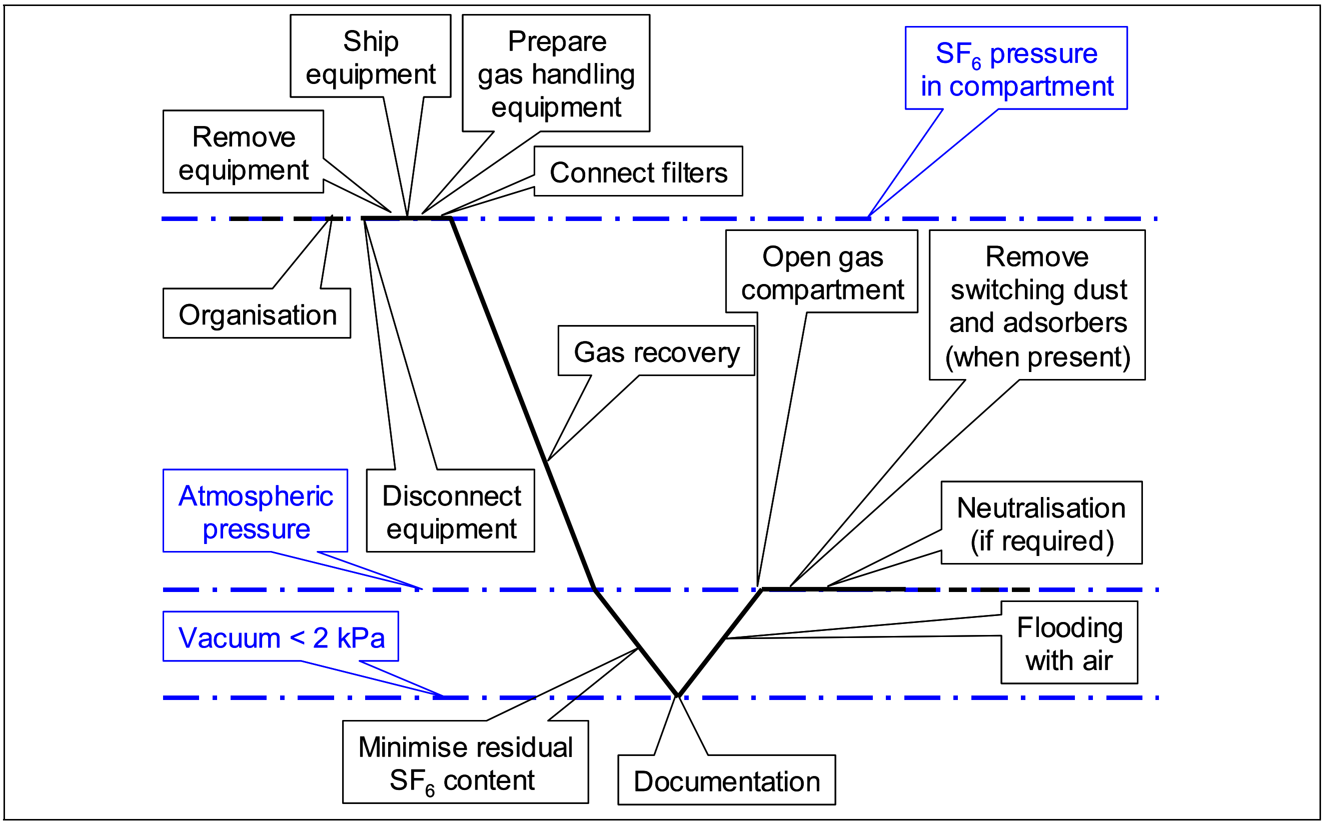


Table 21: Operational description for SF_6 recovery at the end-of-life disposal when the sealed pressure system is dismantled.

Step		Procedure
1	Organisation	Make arrangements with the manufacturer or a qualified service company for off-site SF_6 recovery/end-of-life disposal of the equipment if required.
2	Disconnection of equipment	Disconnect primary and secondary wiring
3	Removal of the equipment	Remove the sealed pressure system
4	Shipping of the equipment	Transportation to the manufacturer or to the qualified service company shall be done in accordance to international and local regulations, as described in paragraph 3.8.3.
5	Prepare gas handling equipment	Check that the gas reclaimer is working properly, the filters and pre-filters are still active and the gas connections are clean and dry to avoid contamination. Check the validity of the calibration of instruments subject to calibration.
6	Connect filters	Connect the pre-filter between the gas compartment and the compressor and the filter between the compressor and the storage container.
7	Connect additional pre-filter (only for heavily arced SF_6)	Connect an additional pre-filter at the inlet of the gas reclaimer.
8	Connect SF_6 compartment	Use dedicated tools and follow the manufacturer's instructions to connect the SF_6 compartment. In other cases, tight drilling systems shall be used.
9	Gas 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 1].
10	Reduce residual SF_6 content	Connect the auxiliary compressor stage and leave it running until a pressure smaller than 2 kPa is reached [note 2].
11	Flooding with air	Detach the compressor and let the air enter slowly into the gas compartment.
12	Settling down of switching dust (only for heavily arced SF_6)	Wait until the remaining switching dust has settled down in the gas compartment.
13	Open the gas compartment	Carefully open the gas compartment. Apply safety rules according to paragraph 3.6.
14	Remove switching dust, removable parts, and adsorbers when present	Immediately use vacuum cleaner or wipe with a clean lint free rag to collect the dust, if present. Place adsorbers and removable parts in a plastic bag. Seal the plastic bags with tape and tag them.
15	Neutralisation, if required	If switching dust was collected, use 10% soda solution or equivalent to wash and neutralise all parts and then wash with clean water.
16	Documentation	Record the at least the serial number of the equipment, the date of dismantling and the quantity of gas recovered in kg.
Note 1:	In the case of liquid storage the weight of the storage container shall be controlled in order to avoid overfilling. The filling factor is smaller than 0.8 kg/litre for safety reasons.	
Note 2:	A SF_6 residual pressure in the gas compartment lower than 2 kPa applied to MV power equipment, according to Appendix 1.	

5 SF_6 HANDLING EQUIPMENT DESCRIPTION MODULES

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

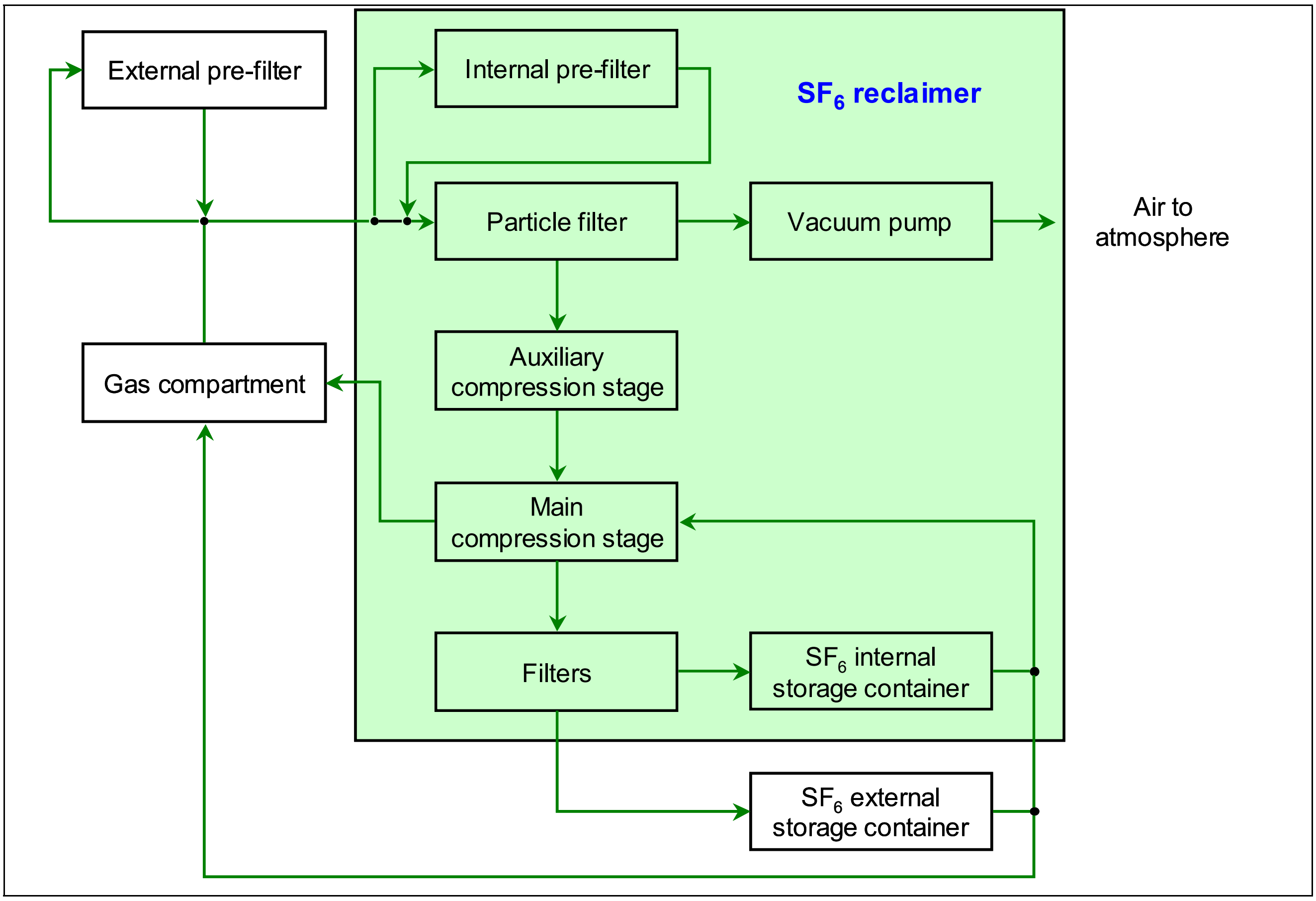
5.1 Gas reclaimers

The appropriate type and size of the reclaimer should be chosen according to the gas quantity to be handled.
The typical functions of a standard SF_6 reclaimer are as follows:

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

Figure 11 shows the basic functional scheme of a general purpose SF_6 reclaimer.

Figure 11: Functional scheme of a general purpose SF_6 reclaimer.



The requirements for each component of a SF_6 reclaimer are discussed in the following paragraphs.

5.1.1 Pre-filtering unit

A pre-filtering unit, either stand-alone or internal, is required to recover both normally and heavily arced SF_6. The reactive gaseous decomposition products are acid compounds and could damage the gas 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 gas-handling device, but the pre–filtering capacity could be considerably higher.
Recommended major characteristics are:

- Pore size 10 μm (low through-flow resistance);

- Residual moisture lower than 200 ppmv;
- Residual reactive gaseous decomposition products lower than 200 ppmv.

5.1.2 Filtering unit

Filtering units are required to remove the reactive gaseous decomposition products before they are stored – hence allowing for the re-use of SF_6. These filtering units are installed in the SF_6 reclaimer.

Table 22 shows typical filter types used during SF_6 reclaiming.

Table 22: Typical filter types used during SF_6 reclaiming.

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

The following paragraphs give further details.

5.1.2.1 Particle filter

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

5.1.2.2 Gas/moisture filters

Appropriate filters can adsorb moisture and reactive gaseous decomposition products. They are mainly used in combination with the particle filter. Molecular sieves with a pore size smaller than 0.5 μm are used. In case of a bigger pore size is used, under certain conditions, thermodynamic reactions can occur resulting in severe filter overheating.
Soda lime ($NaCO_3$) shall not be used as a filter material for SF_6 as, upon contact with certain reactive gaseous decomposition products, produces CO_2, which is difficult to remove from SF_6.

5.1.2.3 Oil filter

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

5.1.3 Vacuum pump

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

The residual pressure at the inlet of the vacuum pump should be lower than 300 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 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 1000 l, a connecting diameter of 20 mm or ¾" is recommended. If smaller diameters are used, the evacuation process is considerably extended and the use of a vacuum pump with a higher capacity is not useful.

The vacuum pump is equipped with a vacuum pressure gauge. The resolution of the vacuum pressure gauge shall be at least lower than 100 Pa. A resolution lower than 10 Pa is recommended.

Vacuum gauges independent of the gas type are generally recommended. Thermal vacuum sensors are dependent on the gas type. They react with SF_6 – vapours in different ways and can give a false vacuum reading.
A valve is recommended to shut off the connection between the gas compartment and the vacuum pump. The valve shall close at least manually (automatically is recommended) after having turned off the vacuum pump to avoid oil diffusion into the gas compartment.

5.1.4 Compressor

When the SF_6 pressure in the gas 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.
A 2.5 MPa rated outlet pressure of the compressor is sufficient to store SF_6 in a gaseous form (5 MPa pressure is recommended). An additional cooling device may be used to speed up gas recovery.
A very important parameter for choosing a compressor is the pressure at the outlet divided by the pressure at the inlet (compression ratio). State-of-the-art compressor stages are optimised for a compression ratio 1:100 for technological reasons.
As the pressure in the gas compartment may vary within a very wide range, a dual compressor shall be used:

- The **main compression stage**, 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. Almost all kinds of piston type compressors can be used, however those which are dry-running and hermetically sealed are preferred to reduce the possibility of SF_6 leaks and oil contamination.
- The **auxiliary compression stage**, connected in series when needed, operates between the pressure in the gas compartment and the pressure at the inlet of the main compressor.

State-of the-art compressors can achieve 100 Pa pressure at the inlet. Preferred compressors are of dry-running and hermetically sealed.

5.1.5 Storage container

Commercial pressure vessels or special storage containers for used SF_6 are available as storage containers. They are mobile, stationary or installed in the gas reclaimer. Only specially approved storage containers or gas cylinders for storage and/or transportation of used SF_6 are allowed. These are described in paragraph 3.8. 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 must be observed. For storage containers with liquid SF_6 storage a nominal pressure of 5 MPa is recommended.

5.1.6 Evaporator/heater

If SF_6 is stored in liquid form and used as a gas, icing/frosting of the storage container takes place when large gas quantities are handled in a short time. Cylinder heaters and evaporators are commercially available. The evaporator receives liquid SF_6 from the storage container and shall be designed so that no liquid can reach the gas compartment. The storage container heaters shall be designed to avoid accidental overheating. It is recommended that the gas temperature is always kept lower than 60 °C.

5.1.7 Gas and hose connections

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

5.1.8 Gas piping and pipe junctions

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

5.1.9 Control instruments

Control gauges shall be provided to show the gas pressure in the gas 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 gas-handling device. Accuracy and resolution of the gauges should be adequate to allow preservation of safe operating conditions.

5.1.10 Safety valves

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

5.2 Personal protective equipment

Safety shoes and helmets must be used according to local safety regulations. In addition to that, protective equipment against SF_6 decomposition products to consider when accessing a gas compartment is briefly described in the following paragraphs.

5.2.1 Skin protection

Protective gloves shall be resistant to solvents, acids and liquid tight. They are usually made of nitril or neoprene. In addition to protective gloves, the use of protective creams is recommended.

5.2.2 Eye protection

Safety goggles assure protection against gas and fine dust.

5.2.3 Breathing protection

5.2.3.1 Breathing protective mask

Normal mask protecting nose and mouth against dust.

5.2.3.2 Full face mask

Gas tight mask protecting eyes, nose and mouth with changeable active charcoal filter.

5.2.4 Overall protection

Single use dust proof protective clothes to wear over normal clothes, shoe covers, hair cap.

5.3 Devices for gas measurement on-site

5.3.1 Control instruments

Pressure/density gauges are used to compare the SF_6 pressure in the gas compartment to the SF_6 rated filling pressure of each compartment. The ambient temperature shall be taken into account to permit proper comparison.

Table 23 gives a survey on the SF_6 control instruments including recommended measuring range and minimum accuracy.

Table 23: On-site SF_6 measuring devices

Device	Quantity	Range	Minimum accuracy
SF_6 pressure gauge	Pressure	0 to 1 MPa	±10 kPa
Thermometer	Temperature	-25 to 50 °C	±1 °C
Dew point meter	Moisture	Dew point: -50 to 0°C	±2 °C
SF_6 content measuring device	SF_6/N_2, SF_6/air	0 to 100% by vol.	±1 % vol.
Reaction tubes	SO_2 Oil mist	1 to 25 ppmv 0.16 to 1.6 ppmv	±15 %

Gas quality measurements can be made under laboratory conditions and on-site. The following section describes the most commonly applied on-site control instruments for the determination of:

- The moisture content/dew point,
- The SF_6 content/quantity of inert gases;
- The residual quantity of reactive gaseous decomposition products/residual acidity content.

5.3.1.1 Dew point meters

The moisture content can be measured with different measuring principles and measuring instruments. It is mainly measured as dew point (dew = droplet) and expressed in °C.
Desirable features of dew point meters are:

- Sensor resistant to oil traces and corrosive gases;
- Permeation resistant connecting pipes using self-sealing valve connections;
- Portable;
- Calibrated or capable of field calibration;
- SF6 gas release less than ~6 g per measurement;
- Average time to obtain the readout less than 5 minutes.

5.3.1.2 SF_6 content measuring devices

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

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

- Response time < 1 min;
- No recalibration required;
- Portable;
- SF_6 gas release less than 3 g per measurement.

5.3.1.3 Analysers of reactive gaseous decomposition products

Desirable features for analysers of reactive gaseous decomposition products are:

- Calibration for SO_2 and SOF_2;
- Connecting pipes resistant to reactive gaseous decomposition products and utilising self sealing valve connections;
- Portable;
- SF_6 gas release less than ~6 g per measurement.

Reaction Tubes
Reaction tubes sensitive to SO_2 shall be used, as the gas remains for quite a long time in the SF_6 environment. These portable field instruments change their initial colour if SF_6 containing SO_2 is fed through them. SO_2 reaction tubes are also sensitive to SOF_2. A small amount of SF_6 from the equipment (~6 g) is needed. That gas sample is then released through the reaction tube to perform the measurement. A measuring range from 0 to 25 ppmv is recommended.

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

Electronic and electro-chemical SO_2 sensors
Electronic and electro-chemical SO_2 sensors have been developed but have not yet been tested in SF_6 insulated power technology.

Ion Mobility Spectrometers
A new method is at a very advanced development stage. It will be the state-of-the-art as soon as it is available on the market. It is based on an IMS (Ion Mobility Spectrometer) calibrated to detect the total quantity of reactive gaseous decomposition products as a whole and not only as the sum of SO_2 and SOF_2. For the time being, this method requires to be consolidated before being industrially adopted.

Today, it seems that an IMS analyser will have the following advantages over reaction tubes:

- Faster response time (approx. 10 seconds);
- Smaller quantity of gas used (~2.5 g);
- Lower detection threshold (0.5 ppmw);
- No shelf live limitations of tubes;
- Possibility of on-line monitoring;
- Measuring results will be in electronic form, ready to be downloaded for automated record keeping;
- IMS may be combined with moisture and purity analysers in one device.

On the contrary, it seems that the disadvantages of an IMS analysers over reaction tubes will be:

- Higher cost;
- Needs to be flushed with small amount of pure SF_6 prior to measurement.

5.4 Cylinder for gas samples

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

5.5 Gas piping and pipe junctions

For piping installed at electrical equipment or in buildings, piping and fittings made of copper, aluminium or stainless steel can be used. Stainless steel piping and fittings are recommended if normally arced or heavily arced gas is handled.
Piping connections are a common source of SF_6 leaks. Therefore it is recommended that connections be regularly checked for leakage.
Safety valves shall be inserted in the SF_6 cycle to limit the gas pressure in parts where this is required.

APPENDIX 1

THEORETICAL CONSIDERATIONS FOR SF_6 HANDLING

The following paragraphs present some theoretical considerations for best practices for SF_6 handling. The focus is on both air and SF_6 residual pressure in gas compartments vs. SF_6 dilution and handling losses, respectively.

1 Air residual pressure vs. SF_6 dilution and moisture content

When considering SF_6 dilution due to the air residual content in the gas compartment, the following aspects should be considered:

- Inert gases can be separated by compressing SF_6 down to liquefaction. It should be noted that this requires more expensive gas reclaimers;
- The new concept of supply of "technical grade SF_6", which will be introduced by the 2nd edition of IEC 60376 [2], allows up to 1% vol. air and 0.4% vol. CF_4, i.e. 1.4% vol. for the sum of both inert gases;
- The purity requirements for SF_6 re-use and recycling that are specified by IEC 60480 [3] allow up to 3% vol. for the sum of both air and CF_4;
- Each time a gas compartment is evacuated down to the air residual pressure p_{air} and filled with SF_6 up to the SF_6 rated filling pressure p_{SF6}[1], the gas is diluted by a factor $1-\frac{p_{air}}{p_{SF_6}}$;

In case of many complete handling operations (handling operation = evacuation + filling), the following equation applies:

$$1-c_f=(1-c_i)\left(1-\frac{p_{air}}{p_{SF_6}}\right)^n$$

where:

- c_i is the IEC 60376 [2] limit for air and CF_4 (1.4%);
- c_f is the IEC 60480 [3] limit for air and CF_4 (3.0%);
- p_{SF6} is the SF_6 rated filling pressure;
- p_{air} is the air residual pressure after evacuation;
- n is the number of complete handling operations.

Table 24 gives the number of handling operations required, starting from "technical grade SF_6", to reach the SF_6 re-use limit specified by IEC 60480 [3], as a function of the air residual content and the SF_6 rated filling pressure.

[1] Typical SF_6 rated filling pressures are: 100 to 150 kPa for MV insulation, ~300 kPa for MV breakers, ~500 kPa for HV insulation, and ~700 kPa for HV breakers.

Table 24: Maximum number of handling operations vs. air residual pressure and SF_6 rated filling pressure.

[# of times]	SF_6 rated filling pressure [kPa]				
Air residual pressure [Pa]	100	150	300	500	700
100	16	24	49	81	114
200	8	12	24	40	57
300	5	8	16	27	38
400	4	6	12	20	28
500	3	4	9	16	22
600	2	4	8	13	19
700	2	3	7	11	16
800	2	3	6	10	14
1000	1	2	4	8	11

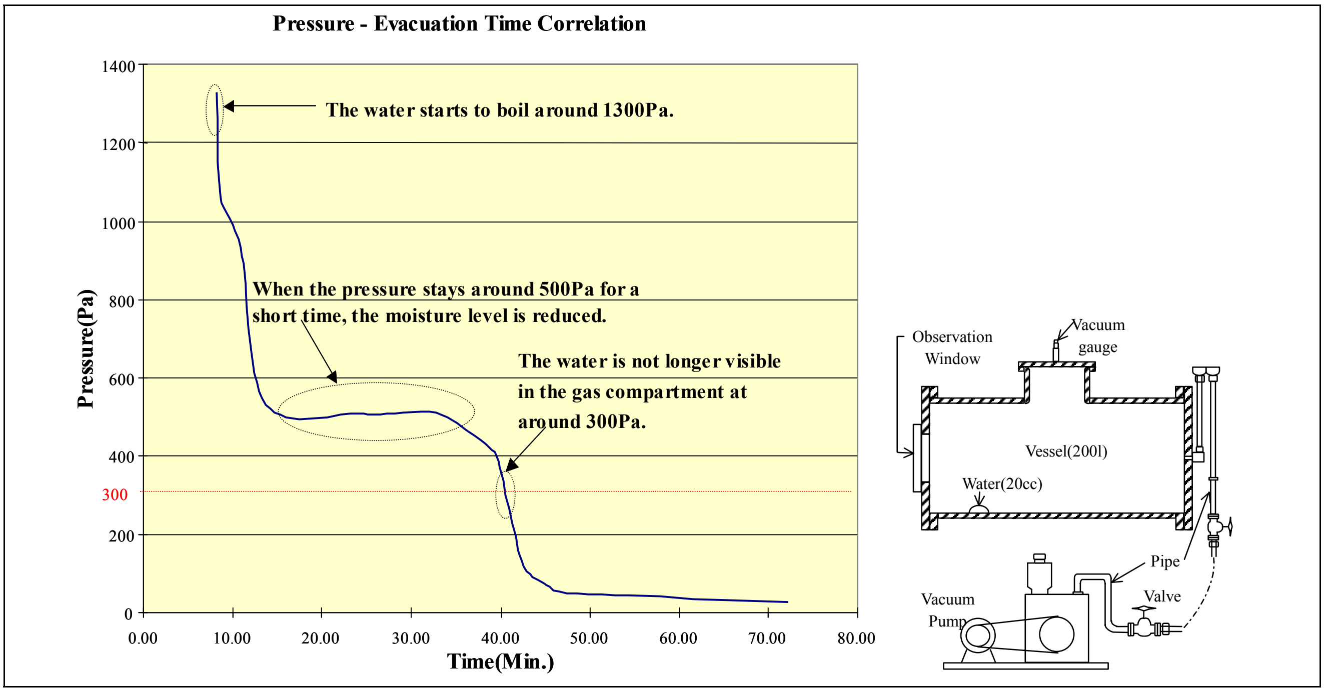
State-of-the-art MV equipments have a typical SF_6 rated filling pressure not greater than 300 kPa, they are sealed pressure systems (commercially denominated as “sealed for life”), and require no SF_6 handling on-site. Therefore there is no practical need to reduce p_{air} in order to permit a high number of handling operations in the low-end part of the p_{SF6} range.

The vacuum level for evacuation is set to be smaller than 300 Pa for at least 1 hour from the viewpoint of getting rid of moisture of each gas compartment enough.

Figure 12 shows the evacuation experiment in gas compartment (200 litres) containing 20 cm^3 of water. Looking from the observation window into the gas compartment, it is possible to notice that:

- The water starts to boil around 1300 Pa;
- The pressure remains around 500 Pa for a short time and the moisture level is reduced;
- When the pressure is smaller than 300 Pa the water is no longer visible in the gas compartment.

Figure 12: Correlation between the pressure in a typical gas compartment and the evacuation time during air evacuation



The top limit concerning the residual pressure in any kind of gas compartment prior to filling is deduced from IEC 60694: dew point not higher than –5 °C, corresponding to a moisture partial pressure of 400 Pa.

2 SF_6 residual pressure vs. SF_6 handling losses

The SF_6 handling loss per handling operation can be easily evaluated, as it is the ratio between the SF_6 residual pressure p_r and the SF_6 rated filling pressure p_{SF6}. This is given in Table 25.

Table 25: SF_6 handling loss in % per handling operation vs. SF_6 residual pressure and SF_6 rated filling pressure.

[% vol.]		SF_6 rated filling pressure [kPa] 100	150	300	500	700
SF_6 residual pressure [Pa]	100	0.10	0.07	0.03	0.02	0.01
	200	0.20	0.13	0.07	0.04	0.03
	500	0.50	0.33	0.17	0.10	0.07
	1000	1.00	0.67	0.33	0.20	0.14
	2000	2.00	1.67	0.67	0.40	0.29
	5000	5.00	3.33	1.67	1.00	0.71
	10000	10.00	6.67	3.33	2.00	1.43
	20000	20.00	16.7	6.67	4.00	2.86

State-of-the-art MV equipments require no SF_6 handling on site. A SF_6 residual pressure not higher than 2 kPa is required to assure reaching a target of 2% handling losses at the end-of-life disposal when the equipment is dismantled, assuming a SF_6 rated filling pressure of approx. 100 kPa. The same SF_6 residual pressure of 2 kPa is suggested for MV closed pressure systems.

Considering HV equipment with a typical rated filling pressure of 500 kPa and a SF_6 residual pressure of 2 kPa, 0.4% handling losses are achieved. However, state-of-the-art handling equipment is capable of recovering SF_6 down to less than 100 Pa in the gas compartment, achieving a further environmental benefit.

APPENDIX 2

MOISTURE MEASUREMENT UNITS AND CONVERSIONS

Several physical quantities and units are used to measure the amount of moisture in a GIS compartment. They are:

- Moisture partial pressure, usually in pascal [Pa];
- Moisture volume concentration, usually in parts per million by volume [ppmv];
- Moisture mass concentration, usually in part per million by weight [ppmw];
- Dew point, usually in degree centigrade [°C];
- Absolute humidity, usually in grams per cubic metre [g/m^3];
- Relative humidity, usually in percentage [%]

The following paragraphs define and give a short explanation of each measure. Conversion formulas and tables are also given.

1 Moisture partial pressure [Pa]

The primary physical quantity characterising the moisture level in a gas compartment is the moisture partial pressure. This is a linear measure of the moisture level and is independent of the pressure of the background gas as well as its nature. As the moisture partial pressure is a pressure, the unit is pascal [Pa].
The law of perfect gases can be successfully applied:

$$p_{H_2O} = \frac{n_{H_2O}}{V} RT = \frac{m_{H_2O}}{V} \frac{R}{M_{H_2O}} T \qquad (1)$$

where:

- p_{H2O} is the moisture partial pressure [Pa];
- n_{H2O} is the number moles of moisture contained in the gas compartment;
- V is the volume of the gas compartment [m^3];
- $R = 8.3143 \frac{J}{molK}$ is the universal constant of perfect gases;
- T is the absolute temperature [K] to which the moisture partial pressure is referred, typically 293.16 K, corresponding to 20 °C;
- m_{H2O} is the mass of moisture contained in the gas compartment [g];
- $M_{H_2O} = 18 \frac{g}{mol}$ is the molar mass of water.

2 Absolute humidity AH [g/m^3]

The absolute humidity AH is the mass of moisture contained in the gas compartment divided by the volume of the gas compartment. This is a linear measure of the moisture level and is independent of the pressure of the background gas as well as its nature. As the absolute humidity is a mass density, the unit is [g/m^3].
The following equation applies:

$$AH = \frac{m_{H_2O}}{V} = \frac{p_{H_2O}}{T} \frac{M_{H_2O}}{R} \qquad (2)$$

where:

- AH is the absolute humidity [g/m^3];
- m_{H2O} is the mass of moisture contained in the gas compartment [g];
- V is the volume of the gas compartment [m^3];
- p_{H2O} is the moisture partial pressure [Pa];

- T is the absolute temperature [K] to which the moisture partial pressure is referred, typically 293.16 K, corresponding to 20 °C;
- $M_{H_2O} = 18 \frac{g}{mol}$ is the molar mass of water;
- $R = 8.3143 \frac{J}{molK}$ is the universal constant of perfect gases.

3 Moisture volume concentration [ppmv]

The moisture volume concentration c_V is the volume occupied by the moisture contained in the gas compartment at the SF_6 rated filling pressure divided by the volume of the gas compartment. This is also the ratio between the moisture partial pressure and the SF_6 rated filling pressure. The recommended unit is ppmv, parts per million by volume.

$$c_V = \frac{V_{H_2O}}{V} = \frac{RT}{V} \frac{n_{H_2O}}{p_{SF_6}} 10^3 = \frac{p_{H_2O}}{p_{SF_6}} 10^3 = \frac{n_{H_2O}}{n_{SF_6}} 10^6 = \frac{m_{H_2O}}{m_{SF_6}} \frac{M_{SF_6}}{M_{H_2O}} 10^3 \quad (3)$$

where:

- c_V is the moisture volume concentration [ppmv];
- V_{H2O} is the volume occupied by the moisture contained in the gas compartment at the SF_6 rated filling pressure [cm^3];
- V is the volume of the gas compartment [m^3];
- $R = 8.3143 \frac{J}{molK}$ is the universal constant of perfect gases;
- T is the absolute temperature [K] to which both the SF_6 rated filling pressure and the moisture partial pressure are referred, typically 293.16 K, corresponding to 20 °C;
- n_{H2O} is the number moles of moisture contained in the gas compartment;
- p_{SF6} is the SF_6 rated filling pressure [kPa];
- p_{H2O} is the moisture partial pressure [Pa];
- n_{SF6} is the number moles of SF_6 contained in the gas compartment;
- m_{H2O} is the mass of moisture contained in the gas compartment [g];
- m_{SF6} is the mass of SF_6 contained in the gas compartment [kg];
- $M_{SF_6} = 146 \frac{g}{mol}$ is the molar mass of SF_6;
- $M_{H_2O} = 18 \frac{g}{mol}$ is the molar mass of water.

4 Moisture mass concentration [ppmw]

The mass concentration c_M is the ratio between the mass of the moisture and the SF_6 contained in the gas compartment. The most common unit is ppmw, parts per million by weight.

$$c_M = \frac{m_{H_2O}}{m_{SF_6}} 10^3 = \frac{p_{H_2O}}{p_{SF_6}} \frac{M_{H_2O}}{M_{SF_6}} 10^3 = \frac{M_{H_2O}}{M_{SF_6}} c_V \quad (4)$$

where:

- c_M is the mass concentration [ppmw];
- m_{H2O} is the mass of moisture contained in the gas compartment [g];
- m_{SF6} is the mass of SF_6 contained in the gas compartment [kg];
- p_{H2O} is the moisture partial pressure [Pa];
- p_{SF6} is the SF_6 rated filling pressure [kPa];

- $M_{H_2O} = 18 \frac{g}{mol}$ is the molar mass of water;
- $M_{SF_6} = 146 \frac{g}{mol}$ is the molar mass of SF_6;
- c_V is the moisture volume concentration [ppmv].

5 Dew point [°C]

Condensation of moisture as liquid (droplets = dew) or solid (ice) occurs when the moisture partial pressure reaches a critical value, termed the moisture saturation pressure. The moisture saturation pressure is a non-linear function of the temperature only. It has no relation to the pressure of the background gas or its nature.
The moisture saturation pressure vs. dew point is an experimental curve. It is used to relate the dew point and moisture partial pressure. The Smithsonian Meteorological Tables define the worldwide interpolation curves, depending on the temperature interval:

For temperatures ranging between –100 °C and 0 °C:

$$\log_{10} \frac{p_w}{610.71} = -9.09718\left(\frac{273.16}{T_w} - 1\right) - 3.56654\log_{10}\frac{273.16}{T_w} + 0.876793\left(1 - \frac{T_w}{273.16}\right) \quad (5)$$

For temperatures ranging between 0 and +100 °C:

$$\log_{10} \frac{p_w}{101325.6} = -7.90298\left(\frac{373.16}{T_w} - 1\right) + 5.02808\log_{10}\frac{373.16}{T_w} + \\ -1.3816 \cdot 10^{-7}\left(10^{11.344\left(1-\frac{T_w}{373.16}\right)} - 1\right) + 8.1328 \cdot 10^{-3}\left(10^{-3.49149\left(\frac{373.16}{T_w}-1\right)} - 1\right) \quad (6)$$

where:

- p_w is the moisture saturation pressure [Pa];
- T_w is the absolute dew point [K]; $T_w = 273.16 + t_w$ where t_w is the dew point in [°C];

Table 26 gives the non linear relationship between the dew point and the moisture saturation pressure in the temperature range –60 °C to +60°C in steps of 1 °C.

Table 26: Moisture saturation pressure in the temperature range –60 °C to +60 °C in steps of 1 °C

Dew point t_w [°C]	Moisture saturation pressure p_w [Pa]		Dew point t_w [°C]	Moisture saturation pressure p_w [Pa]		Dew point t_w [°C]	Moisture saturation pressure p_w [Pa]
-60	**1.1**		**-20**	**103**		**20**	**2337**
-59	1.2		-19	114		21	2486
-58	1.4		-18	125		22	2643
-57	1.6		-17	137		23	2809
-56	1.8		-16	151		24	2983
-55	2.1		-15	165		25	3167
-54	2.4		-14	181		26	3361
-53	2.7		-13	198		27	3565
-52	3.1		-12	217		28	3780
-51	3.5		-11	238		29	4006
-50	**3.9**		**-10**	**260**		**30**	**4243**
-49	4.4		-9	284		31	4493
-48	5.0		-8	310		32	4755
-47	5.7		-7	338		33	5031
-46	6.4		-6	368		34	5320
-45	7.2		-5	401		35	5624
-44	8.1		-4	437		36	5942
-43	9.1		-3	476		37	6276
-42	10.2		-2	517		38	6626
-41	11.5		-1	562		39	6993
-40	**12.8**		**0**	**611**		**40**	**7378**
-39	14		1	657		41	7780
-38	16		2	705		42	8202
-37	18		3	758		43	8642
-36	20		4	813		44	9103
-35	22		5	872		45	9586
-34	25		6	935		46	10089
-33	28		7	1001		47	10616
-32	31		8	1072		48	11166
-31	34		9	1147		49	11740
-30	**38**		**10**	**1227**		**50**	**12340**
-29	42		11	1312		51	12970
-28	47		12	1402		52	13620
-27	52		13	1497		53	14300
-26	57		14	1598		54	15010
-25	63		15	1704		55	15750
-24	70		16	1817		56	16520
-23	77		17	1937		57	17320
-22	85		18	2063		58	18150
-21	94		19	2196		59	19020
-20	**103**		**20**	**2337**		**60**	**19930**

6 Relative humidity RH [%]

The ratio between the partial pressure and the saturation pressure of moisture, at the same reference temperature, is the relative humidity. The relative humidity is an implicit and non-linear function of the temperature, only. It has no relation to the pressure of the background gas or its nature. The typical unit is %.

$$RH = 100\frac{p_{H_2O}}{p_w} \tag{7}$$

where:

- p_{H2O} is the moisture partial pressure [Pa] at the reference temperature t;
- p_w is the moisture saturation pressure [Pa] at the reference temperature t.

7 Maximum moisture content in equipment (IEC 60694, future IEC 62271-1)

IEC 60694 states that the dew point in electric power equipment, at the SF_6 rated filling pressure, is not higher than –5 °C for a measurement at 20 °C. Therefore the moisture partial pressure in electric power equipment, at the SF_6 rated filling pressure, shall not exceed the limit of 401 Pa (see Table 26). The conversion to the recommended unit, given by eq. (3), is an inverse function of the SF_6 rated filling pressure. It is given in Table 27 for a SF_6 rated filling pressure range of 100 kPa to 850 kPa in steps of 10 kPa.

Table 27: Maximum moisture content vs. SF_6 rated filling pressure (IEC 60694, future IEC 62271-1)

SF_6 rated filling pressure p_{SF6} [kPa]	**Maximum moisture content** [ppmv]		**SF_6 rated filling pressure** p_{SF6} [kPa]	**Maximum moisture content** [ppmv]		**SF_6 rated filling pressure** p_{SF6} [kPa]	**Maximum moisture content** [ppmv]
100	**4010**		**350**	**1145**		**600**	**670**
110	3650		360	1115		610	655
120	3340		370	1085		620	645
130	3080		380	1055		630	635
140	2860		390	1030		640	625
150	**2670**		**400**	**1005**		**650**	**615**
160	2510		410	980		660	610
170	2360		420	955		670	600
180	2230		430	935		680	590
190	2110		440	910		690	580
200	**2010**		**450**	**890**		**700**	**575**
210	1910		460	870		710	565
220	1820		470	855		720	555
230	1740		480	835		730	550
240	1670		490	820		740	540
250	**1600**		**500**	**800**		**750**	**535**
260	1540		510	785		760	530
270	1490		520	770		770	520
280	1430		530	755		780	515
290	1380		540	745		790	510
300	**1340**		**550**	**730**		**800**	**500**
310	1290		560	715		810	495
320	1250		570	705		820	490
330	1220		580	690		830	485
340	1180		590	680		840	475
350	**1150**		**600**	**670**		**850**	**470**

8 Conversion to moisture volume concentration [ppmv]

8.1 From moisture partial pressure [Pa] to moisture volume concentration [ppmv]

Eq. (3) applies:

$$c_V = \frac{p_{H_2O}}{p_{SF_6}} 10^3 \qquad (8)$$

where:

- c_V is the moisture volume concentration [ppmv];
- p_{H2O} is the moisture partial pressure [Pa];
- p_{SF6} is the SF_6 rated filling pressure [kPa].

The conversion to the moisture volume concentration is given in Table 28.

Table 28: Conversion table between moisture partial pressure [Pa] and moisture volume concentration [ppmv] for typical values of SF_6 rated filling pressure [kPa].

[ppmv]	SF_6 rated filling pressure [kPa]								
Moisture partial pressure [Pa]	100	150	200	300	400	500	600	700	850
1	**10.0**	**6.67**	**5.00**	**3.33**	**2.50**	**2.00**	**1.67**	**1.43**	**1.18**
1.5	15.0	10.0	7.50	5.00	3.75	3.00	2.50	2.14	1.76
2	20.0	13.3	10.0	6.67	5.00	4.00	3.33	2.86	2.35
3	30.0	20.0	15.0	10.0	7.50	6.00	5.00	4.29	3.53
4	40.0	26.7	20.0	13.3	10.0	8.00	6.67	5.71	4.71
5	50.0	33.3	25.0	16.7	12.5	10.0	8.33	7.14	5.88
7	70.0	46.7	35.0	23.3	17.5	14.0	11.7	10.0	8.24
10	**100**	**66.7**	**50.0**	**33.3**	**25.0**	**20.0**	**16.7**	**14.3**	**11.8**
15	150	100	75.0	50.0	37.5	30.0	25.0	21.4	17.6
20	200	133	100	66.7	50.0	40.0	33.3	28.6	23.5
30	300	200	150	100	75.0	60.0	50.0	42.9	35.3
40	400	267	200	133	100	80.0	66.7	57.1	47.1
50	500	333	250	167	125	100	83.3	71.4	58.8
70	700	467	350	233	175	140	117	100	82.4
100	**1000**	**667**	**500**	**333**	**250**	**200**	**167**	**143**	**118**
150	1500	1000	750	500	375	300	250	214	176
200	2000	1330	1000	667	500	400	333	286	235
300	3000	2000	1500	1000	750	600	500	429	353
400	4000	2670	2000	1330	1000	800	667	571	471

8.2 From absolute humidity [g/m3] to moisture volume concentration [ppmv]

By substituting eq. (2) in eq. (3), the following equation is obtained

$$c_V = 10^3 \frac{R}{M_{H_2O}} \frac{T}{p_{SF_6}} AH \qquad (9)$$

where:

- c_V is the moisture volume concentration [ppmv];
- $R = 8.3143 \frac{J}{molK}$ is the universal constant of perfect gases;
- $M_{H_2O} = 18 \frac{g}{mol}$ is the molar mass of water.
- T is the absolute temperature [K] to which the SF_6 rated filling pressure is referred, typically 293.16 K, corresponding to 20 °C;
- p_{SF6} is the SF_6 rated filling pressure [kPa];
- AH is the absolute humidity [g/m^3].

Substituting the values for R and M_{H2O} we obtain:

$$c_V = 10^3 \frac{8.3143}{18} \frac{(273.16 + t)}{p_{SF_6}} AH = 461.91 \frac{(273.16 + t)}{p_{SF_6}} AH \qquad (10)$$

where:

- c_V is the moisture volume concentration [ppmv];

- t is the ambient temperature [°C];
- p_{SF6} is the SF_6 rated filling pressure [kPa];
- AH is the absolute humidity [g/m^3].

Eq. (9) at the ambient temperature of 20 °C becomes:

$$c_V = \frac{135410}{p_{SF_6}} AH \tag{11}$$

where:

- c_V is the moisture volume concentration [ppmv];
- p_{SF6} is the SF_6 rated filling pressure [kPa];
- AH is the absolute humidity [g/m^3].

The conversion to the moisture volume concentration is given in Table 29.

Table 29: Conversion table between absolute humidity AH [g/m^3] and moisture volume concentration [ppmv] as a function of the SF_6 rated filling pressure [kPa].

[ppmv]	SF_6 rated filling pressure [kPa]								
Absolute humidity AH [g/m^3]	100	150	200	300	400	500	600	700	850
0.007	9.48	6.32	4.74	3.16	2.37	1.90	1.58	1.35	1.12
0.01	**13.5**	**9.03**	**6.77**	**4.51**	**3.39**	**2.71**	**2.26**	**1.93**	**1.59**
0.015	20.3	13.5	10.2	6.77	5.08	4.06	3.39	2.90	2.39
0.02	27.1	18.1	13.5	9.03	6.77	5.42	4.51	3.87	3.19
0.03	40.6	27.1	20.3	13.5	10.2	8.12	6.77	5.80	4.78
0.04	54.2	36.1	27.1	18.1	13.5	10.8	9.03	7.74	6.37
0.05	67.7	45.1	33.9	22.6	16.9	13.5	11.3	9.67	7.97
0.07	94.8	63.2	47.4	31.6	23.7	19.0	15.8	13.5	11.2
0.1	**135**	**90.3**	**67.7**	**45.1**	**33.9**	**27.1**	**22.6**	**19.3**	**15.9**
0.15	203	135	102	67.7	50.8	40.6	33.9	29.0	23.9
0.2	271	181	135	90.3	67.7	54.2	45.1	38.7	31.9
0.3	406	271	203	135	102	81.2	67.7	58.0	47.8
0.4	542	361	271	181	135	108	90.3	77.4	63.7
0.5	677	451	339	226	169	135	113	96.7	79.7
0.7	948	632	474	316	237	190	158	135	112
1	**1350**	**903**	**677**	**451**	**339**	**271**	**226**	**193**	**159**
1.5	2030	1350	1020	677	508	406	339	290	239
2	2710	1810	1350	903	677	542	451	387	319
3	4060	2710	2030	1350	1020	812	677	580	478

8.3 From moisture mass concentration [ppmw] to moisture volume concentration [ppmv]

Eq. (4) applies:

$$c_V = \frac{M_{SF_6}}{M_{H_2O}} c_M = \frac{146}{18} c_M = 8.1111 c_M \tag{12}$$

The conversion table between the moisture mass concentration and the moisture volume concentration is given in Table 30.

Table 30: Conversion table between moisture mass concentration and moisture volume concentration

Moisture concentration			Moisture concentration	
Mass [ppmw]	**Volume** [ppmv]		**Mass** [ppmw]	**Volume** [ppmv]
0.1	**0.811**		7.5	60.8
0.15	1.22		8	64.9
0.2	1.62		8.5	68.9
0.25	2.03		9	73.0
0.3	2.43		9.5	77.1
0.35	2.84		**10**	**81.1**
0.4	3.24		15	122
0.45	3.65		20	162
0.5	4.06		25	203
0.55	4.46		30	243
0.6	4.87		35	284
0.65	5.27		40	324
0.7	5.68		45	365
0.75	6.08		50	406
0.8	6.49		55	446
0.85	6.89		60	487
0.9	7.30		65	527
0.95	7.71		70	568
1	**8.11**		75	608
1.5	12.2		80	649
2	16.2		85	689
2.5	20.3		90	730
3	24.3		95	771
3.5	28.4		**100**	**811**
4	32.4		150	1220
4.5	36.5		200	1620
5	40.6		250	2030
5.5	44.6		300	2430
6	48.7		350	2840
6.5	52.7		400	3240
7	56.8		450	3650
7.5	60.8		500	4060

8.4 From dew point [°C] to moisture volume concentration [ppmv]

Table 26 can be used to obtain the moisture partial pressure and then Table 28 can be used to obtain the moisture volume concentration.
The final result is given in Table 31, and Table 32. These can be used for direct conversion between the dew point [°C] and the moisture volume concentration [ppmv] using the SF_6 rated filling pressure [kPa] as a parameter.

Table 31: Conversion table between dew point [°C] and moisture volume concentration [ppmv] as a function of the SF_6 rated filling pressure [kPa]. The dew point is in the range between –60 °C and –20 °C

[ppmv]		SF_6 rated filling pressure [kPa]								
		100	150	200	300	400	500	600	700	850
Dew point [°C]	**-60**	**10.8**	**7.2**	**5.4**	**3.6**	**2.7**	**2.2**	**1.8**	**1.5**	**1.3**
	-59	12.4	8.2	6.2	4.1	3.1	2.5	2.1	1.8	1.5
	-58	14.1	9.4	7.1	4.7	3.5	2.8	2.4	2.0	1.7
	-57	16.1	10.7	8.1	5.4	4.0	3.2	2.7	2.3	1.9
	-56	18.4	12.3	9.2	6.1	4.6	3.7	3.1	2.6	2.2
	-55	20.9	13.9	10.5	7.0	5.2	4.2	3.5	3.0	2.5
	-54	23.8	15.9	11.9	7.9	5.9	4.8	4.0	3.4	2.8
	-53	27.0	18.0	13.5	9.0	6.8	5.4	4.5	3.9	3.2
	-52	30.7	20.4	15.3	10.2	7.7	6.1	5.1	4.4	3.6
	-51	34.8	23.2	17.4	11.6	8.7	7.0	5.8	5.0	4.1
	-50	**39.3**	**26.2**	**19.7**	**13.1**	**9.8**	**7.9**	**6.6**	**5.6**	**4.6**
	-49	44.5	29.7	22.2	14.8	11.1	8.9	7.4	6.4	5.2
	-48	50.3	33.5	25.1	16.8	12.6	10.1	8.4	7.2	5.9
	-47	56.7	37.8	28.4	18.9	14.2	11.3	9.5	8.1	6.7
	-46	63.9	42.6	32.0	21.3	16.0	12.8	10.7	9.1	7.5
	-45	72.0	48.0	36.0	24.0	18.0	14.4	12.0	10.3	8.5
	-44	81.0	54.0	40.5	27.0	20.2	16.2	13.5	11.6	9.5
	-43	91.0	60.7	45.5	30.3	22.7	18.2	15.2	13.0	10.7
	-42	102	68.1	51.1	34.0	25.5	20.4	17.0	14.6	12.0
	-41	115	76.4	57.3	38.2	28.6	22.9	19.1	16.4	13.5
	-40	**128**	**85.5**	**64.2**	**42.8**	**32.1**	**25.7**	**21.4**	**18.3**	**15.1**
	-39	144	95.8	71.8	47.9	35.9	28.7	23.9	20.5	16.9
	-38	161	107	80.3	53.5	40.2	32.1	26.8	22.9	18.9
	-37	179	120	89.7	59.8	44.9	35.9	29.9	25.6	21.1
	-36	200	133	100	66.7	50.1	40.0	33.4	28.6	23.6
	-35	223	149	112	74.4	55.8	44.7	37.2	31.9	26.3
	-34	249	166	124	82.9	62.2	49.8	41.5	35.5	29.3
	-33	277	185	138	92.3	69.2	55.4	46.1	39.6	32.6
	-32	308	205	154	103	77.0	61.6	51.3	44.0	36.2
	-31	342	228	171	114	85.5	68.4	57.0	48.9	40.3
	-30	**380**	**253**	**190**	**127**	**95.0**	**76.0**	**63.3**	**54.3**	**44.7**
	-29	421	281	211	140	105	84.3	70.2	60.2	49.6
	-28	467	311	233	156	117	93.4	77.8	66.7	54.9
	-27	517	345	258	172	129	103	86.2	73.9	60.8
	-26	572	381	286	191	143	114	95.3	81.7	67.3
	-25	632	422	316	211	158	126	105	90.3	74.4
	-24	698	466	349	233	175	140	116	99.8	82.2
	-23	771	514	385	257	193	154	128	110	90.7
	-22	850	567	425	283	213	170	142	121	100
	-21	937	625	468	312	234	187	156	134	110
	-20	**1032**	**688**	**516**	**344**	**258**	**206**	**172**	**147**	**121**

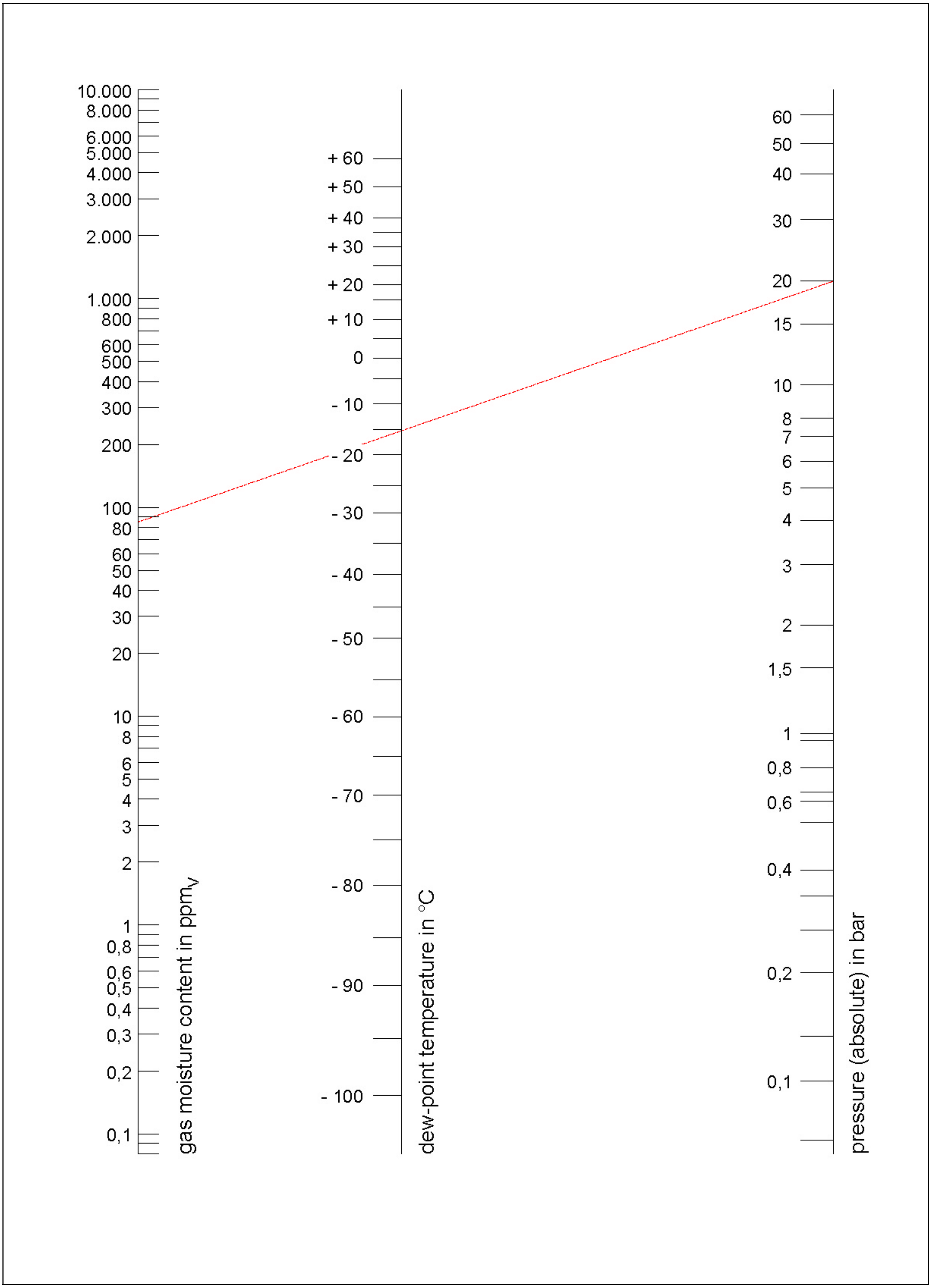
Table 32: Conversion table between dew point [°C] and moisture volume concentration [ppmv] as a function of the SF_6 rated filling pressure [kPa]. The dew point is in the range between –20 °C and –5 °C

[ppmv]	SF_6 rated filling pressure [kPa]								
Dew point [°C]	100	150	200	300	400	500	600	700	850
-20	**1030**	**688**	**516**	**344**	**258**	**206**	**172**	**147**	**121**
-19	1140	757	568	378	284	227	189	162	134
-18	1250	832	624	416	312	250	208	178	147
-17	1370	914	686	457	343	274	229	196	161
-16	1510	1000	753	502	376	301	251	215	177
-15	1650	1100	826	551	413	330	275	236	194
-14	1810	1210	905	604	453	362	302	259	213
-13	1980	1320	992	661	496	397	331	283	233
-12	2170	1450	1090	724	543	434	362	310	255
-11	2380	1580	1190	792	594	475	396	339	279
-10	**2600**	**1730**	**1300**	**866**	**649**	**519**	**433**	**371**	**306**
-9	2840	1890	1420	946	709	567	473	405	334
-8	3100	2060	1550	1030	774	619	516	442	364
-7	3380	2250	1690	1130	845	676	563	483	398
-6	3680	2460	1840	1230	921	737	614	526	433
-5	4010	2680	2010	1340	1000	803	669	574	472

Figure 13 can be also successfully used for direct conversion between the dew point [°C] and the moisture volume concentration [ppmv] using the SF_6 rated filling pressure [bar][1] as parameter.

[1] 1 bar is equal to 10^5 Pa or, better, 100 kPa.

Figure 13: Conversion nomogram between dew point [°C] and moisture volume concentration [ppmv] as a function of the SF_6 rated filling pressure [bar].



8.5 From relative humidity RH for moisture volume concentration [ppmv]

Table 26 is used to obtain the moisture saturation pressure at the reference temperature and then eq. (7) to calculate the moisture partial pressure. Eventually, eq. (8) is used. Table 33 and Table 34 can be used for converting the relative humidity [%] at 0 °C and 20 °C respectively to the moisture volume concentration [ppmv] as a function of the SF_6 rated filling pressure [kPa].

Table 33: Conversion table between relative humidity RH [%] at 0 °C and moisture volume concentration [ppmv] as a function of the SF_6 rated filling pressure [kPa]

[ppmv]		SF_6 rated filling pressure [kPa]								
		100	150	200	300	400	500	600	700	850
Relative humidity RH [%] at 0 °C	5	305	204	153	102	76	61	51	44	36
	10	611	407	305	204	153	122	102	87	72
	15	916	611	458	305	229	183	153	131	108
	20	1220	814	611	407	305	244	204	174	144
	25	1530	1020	763	509	382	305	254	218	180
	30	1830	1220	916	611	458	366	305	262	216
	35	2140	1420	1070	712	534	427	356	305	251
	40	2440	1630	1220	814	611	489	407	349	287
	45	2750	1830	1370	916	687	550	458	393	323
	50	3050	2040	1530	1020	763	611	509	436	359
	55	3360	2240	1680	1120	840	672	560	480	395
	60	3660	2440	1830	1220	916	733	611	523	431
	65	3970	2650	1980	1320	992	794	662	567	467
	70	4270	2850	2140	1420	1070	855	712	611	503

Table 34: Conversion table between relative humidity RH [%] at 20 °C and moisture volume concentration [ppmv] as a function of the SF_6 rated filling pressure [kPa]

[ppmv]		SF_6 rated filling pressure [kPa]								
		100	150	200	300	400	500	600	700	850
Relative humidity RH [%] at 20 °C	1	230	156	117	78	58	47	39	33	27
	2	470	310	230	156	117	93	78	67	55
	3	700	470	350	230	175	140	117	100	82
	4	930	620	470	310	230	187	156	134	110
	5	1170	780	580	390	290	230	195	167	137
	6	1400	930	700	470	350	280	230	200	165
	7	1640	1090	820	550	410	330	270	230	192
	8	1870	1250	930	620	470	370	310	270	220
	9	2100	1400	1050	700	530	420	350	300	250
	10	2300	1560	1170	780	580	470	390	330	270
	11	2600	1710	1290	860	640	510	430	370	300
	12	2800	1870	1400	930	700	560	470	400	330
	13	3000	2000	1520	1010	760	610	510	430	360
	14	3300	2200	1640	1090	820	650	550	470	380
	15	3500	2300	1750	1170	880	700	580	500	410
	16	3700	2500	1870	1250	930	750	620	530	440
	17	4000	2600	1990	1320	990	790	660	570	470
	18	4200	2800	2100	1400	1050	840	700	600	490