
**Guide to the safe use of SF6 in gas
insulated electrical equipment**

Network of Experts for Standardisation



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Paper prepared by:

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UNIPEDE

GUIDE TO THE SAFE USE OF SF₆ IN GAS INSULATED ELECTRICAL EQUIPMENT

FOREWORD

The UNIPEDE Standardisation Specific Committee formed a group of experts (230.9 NORM SF₆) in order to follow up standardisation issues with regard to SF₆. One of the objectives of the group was to prepare a guide to the safe use of SF₆ in gas insulated electrical equipment.

This UNIPEDE Guide sets down an assessment of potential hazards and recommends appropriate safeguards and methods of work to ensure the safety of employees, public and the environment.

AUTHORITY FOR ISSUE

This UNIPEDE Guide is issued under the authority of the UNIPEDE Industry Observatory. This document was approved on 13th May 1998.

STATUS AND IMPLEMENTATION

This UNIPEDE Guide is a recommendation which should be used as a reference when establishing local procedures. National and local Authority regulations and procedures regarding SF₆ shall also be used.

REVISION

Any comments on this UNIPEDE Guide should be forwarded to the UNIPEDE secretariat

GUIDE TO THE SAFE USE OF SF₆ IN GAS INSULATED ELECTRICAL EQUIPMENT

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0 INTRODUCTION

Sulphur Hexafluoride (SF₆) is a gas that has been used in electrical switchgear and controlgear for more than 30 years. Its application is mainly in equipment for rated voltages exceeding 1 kV up to the highest rated voltages for which switchgear and controlgear are manufactured. It is estimated that several millions of the different types of SF₆ -filled units are currently in service.

The main features of SF₆ which determine its suitability for use in electrical equipment are :

- its high dielectric strength ;
- its excellent arc-quenching capabilities ;
- its high chemical stability and non-toxicity.

The long experience with SF₆ in electrical switchgear and controlgear has demonstrated that there are no major problems concerning its use, provided that certain elementary precautions and procedures are established and observed.

A number of international and national standards and codes of practice exist, covering various aspects of SF₆ gas. Additionally, many articles and technical papers on SF₆ and its use have been written. Very few injuries with any permanent consequences have been reported.

SF₆ is used in closed or sealed pressure systems. The small quantity of SF₆ which may leak into the atmosphere does not deplete the ozone layer and currently has a negligible influence on global warming. However, in order to ensure that its contribution remains negligible, it is recommended to avoid any unnecessary release of SF₆ into the atmosphere, since this gas is man-made and has a long lifetime.

The by-products of SF₆ created in switchgear and controlgear by thermal effects (heating, arcing, spark, discharge, etc.) may have toxic properties. However, the real toxicity depends on the concentration in the switchgear and controlgear room and the exposure time. Taking these factors into consideration it is shown that the presence of SF₆ does not impose a greater risk to the operator under normal (operating) or abnormal (internal fault, fire) conditions than the other materials used in any other type of switchgear and controlgear (metals, plastics, etc.), provided the procedures in this document are followed.

1 SCOPE

This Guide is applicable to fully enclosed medium and high voltage electrical equipment which is designed to be filled with SF₆ : i.e. SF₆-filled electrical equipment. This Guide specifies the precautions to be observed to avoid pollution of the environment by correct maintenance and operation of SF₆-filled electrical equipment and give guidance on safety precautions to be taken when handling SF₆ or disposing of SF₆ by-product contaminated waste.

2 DEFINITIONS

There are many different types of switchgear and controlgear which use SF₆ gas as a dielectric and/or arc-quenching medium. For the purpose of this Guide, the following definitions apply :

2.1 Sealed pressure system

For a sealed pressure system, the SF₆ gas is in "sealed-for-life" enclosures, which are never opened during the service life of the equipment.

2.2 Closed pressure system

A closed pressure system, is one in which replenishment of losses due to leakage may be necessary and periodic maintenance involving removal and replacement of the gas is possible.

2.3 New SF₆

SF₆ which complies with the requirements for purity stated in IEC 60376 [3].

2.4 Used SF₆

SF₆ which may have been contaminated by impurities or which has been subjected to operating conditions after energisation of the switchgear and controlgear.

Used SF₆ may contain small quantities of decomposition products, but some of them may have toxic effects. Certain precautions are therefore required when handling used SF₆.

2.5 Enclosed equipment

Equipment using mainly air as the primary insulating medium. The SF₆ is contained in switching enclosures made from metal or cast resin. SF₆-filled medium-voltage circuit-breaker and load-break switch equipment is frequently of this type of construction.

2.6 Gas-Insulated Switchgear (GIS)

High voltage equipment using mainly SF₆ as the primary insulating medium. Compartments within a gas-insulated assembly, containing various functional modules (circuit-breakers, switches, busbars), may be physically isolated from each other, such that each can be regarded as a separate gas enclosure.

2.7 SF₆-Insulated cubicles

Medium-voltage Ring Main Units (RMU) where busbars and switching devices are contained into the same SF₆ insulating enclosure.

2.8 Handling

Any process which might involve contact of workers with new or used SF₆.

This includes removing the gas from an item of switchgear or controlgear either completely or as a sample to be tested, opening a gas-filled enclosure, cleaning out an open enclosure and working inside large enclosures.

2.9 Leakage

Leakage from equipment in service is the unplanned, usually continuous, emission of gas from a sealed or closed system. Leakage occurs at seals and joints and by molecular diffusion through certain enclosure materials. Leakage does not include

releases of gas due to intervention with the systems intended to contain it.

2.10 Rated voltage

Medium voltage : Rated voltages from 1 kV up to and including 52 kV.

High voltage : Rated voltages above 52 kV.

This distinction is made because there are often significant differences in design, construction and size between the two categories.

2.11 Global Warming

The average global temperature of the earth results from a balance between the heating effects of solar radiation and the cooling associated with infra-red radiation from the earth. Some of the infra-red radiation is reflected back to the surface of the earth and therefore does not escape from the atmosphere which induces a relative increasing of the earth's temperature.

2.12 Radiative forcing

Radiative forcing quantifies the net change in the infra-red heat flux and the associated global warming. SF₆ absorbs infra-red radiation. Therefore SF₆ contributes to radiative forcing but its concentration in the atmosphere compared with CO₂ is negligible.[8][11]

3 IDENTIFICATION OF SF₆ AND ITS BY-PRODUCTS

The first point of identification of SF₆ should be the manufacturers name-plate. When equipment containing a large amount of SF₆ is installed, such as G.I.S., in a building, suitable information should be displayed inside the building near to the access point. Reference [11] gives guidance on a suitable notice. IEC 60480 [4] gives guidance to identify SF₆ and its by-products.

4 GENERAL CHARACTERISTICS OF SF₆

Clean, new SF₆ gas has no colour, smell or taste. It is non-combustible, non toxic and is chemically inert at room temperatures.

Precautions for working safely with SF₆ are required for the following reasons:

- a) SF₆ gas is about five times heavier than air and will, if released into the atmosphere in a sufficient quantity, tend to accumulate initially in low-lying areas where there is no natural ventilation and may cause asphyxiation.
- b) SF₆ decomposes at high temperatures. Decomposition may occur if the gas is heated, for example, by fire external to the equipment and will occur if there is an electric arc, spark or other electrical discharge within it. Some of the decomposition products may have toxic effects, but under normal service conditions in switchgear and controlgear these are contained within a well-controlled and enclosed environment.
- c) SF₆ gas, when released into the atmosphere, has a relatively long life [11]

and contributes to radiative forcing.

5 EQUIPMENT DESIGN AND CONSTRUCTION

5.1 Design

SF₆ insulated electrical power equipment is designed for low leakage losses in accordance with the relevant equipment standards [1], [2], [5], [7]. Leakage is essentially due to enclosure porosity, sealing and through associated gas pipework.

At present, a loss rate of 1% per year is specified for SF₆ insulated electrical power equipment. Preliminary data from utilities indicate that actual leakage rates in operating equipment are often substantially lower. Apart from some early poorly designed equipment, leakage rates below 1% are found for first generation equipment (before about 1985). Second generation equipment leakage rates are usually below 0.5% per year. For distribution applications, sealed-for-life equipment is being produced for which leakage rates below 0.1 % per year are obtained. If the equipment is not sealed for life, built in and portable monitoring devices are available to detect gas leakage.

5.2 Typical quantities of SF₆

SF₆ gas in electrical equipment is normally at a pressure of 0.1MPa to 0.9MPa absolute. The quantity varies approximately between 0.1 kilogram in one pole of a medium voltage switching device and several hundreds of kilograms in the largest compartment of a large high voltage GIS substation.

6 EFFECT ON THE ATMOSPHERIC ENVIRONMENT AND THE NEED FOR RECYCLING

6.1 Effect on atmospheric environment

SF₆ has been identified as a “greenhouse gas” having a long atmospheric lifetime. The Kyoto Summit on Climate Change held in December 1997 included SF₆ in the “basket of greenhouse gases”. The present atmospheric concentration of SF₆ is negligible[11]. Therefore, the release of SF₆ should be minimised, especially by recycling and avoidance of deliberate release.

6.2 Recycling

The cost of SF₆ and its effect on the atmospheric environment mean that SF₆ should, wherever possible, be recycled and reused during equipment development, product testing, commissioning, maintenance and repair and decommissioning. It should also be recycled from equipment being phased out, into new equipment.

Successful recycling requires :

- appropriate design of the SF₆ filled equipment for ease of recycling ;
- appropriate facilities and procedures for recycling SF₆.

If appropriate steps need to be taken to recondition SF₆ from unusually heavy contamination (with moisture or decomposition products), they can usually be applied locally using special additional filters.

Guidance on SF₆ recycling is given in references [8][11][12].

7 HANDLING OF SF₆

SF₆ is handled in following circumstances :

- filing of switchgear ;
- maintenance operations ;
- recycling of used gas ;
- decommissioning of SF₆-filled equipment.

Factors to be taken into account when handling SF₆ [12] :

- appropriate gas handling procedures ;
- appropriate gas handling equipment ;
- quantities of contaminants to be expected.

SF₆ could present a danger of asphyxiation due to oxygen deficiency if personnel are working, for example, below ground in ducts or trenches. Therefore there is a need to check for SF₆ concentration before entry.

When maintenance is required, or if gas is inadvertently released into the atmosphere, precautions are needed to ensure the safety of personnel.

The SF₆ reclaiming ability of any user, will in general, be limited to detecting and treating normal case scenarios. The technology to handle special contamination of SF₆ is relatively expensive and requires experience. The user of SF₆ may find it too expensive to provide such facilities by himself but, if so, service providers capable of processing such material should be used.

8 STORAGE AND TRANSPORTATION

8.1 Storage

New gas is supplied in cylinders. The new gas cylinders should not be used for storage of used SF₆ at any time. However appropriately labelled cylinders can be used for storage of SF₆. Cylinders should be specially marked to avoid the mix of used gas with new gas. Used SF₆ gas can be stored at a safe ratio of 1 kg of SF₆ per 1 litre volume by the use of suitably designed simple storage vessels.

8.2 Transportation

For transport of new SF₆, local transport regulations will apply. Some countries have introduced transport regulations for used SF₆. None of the regulations currently in existence explicitly mentions contaminated SF₆, a multilateral agreement has been formed with regard to all non-mentioned gases and gas mixtures.

The main criteria for the transport of used contaminated SF₆ are the corrosive and toxic characteristics of the contaminants and their concentrations. Proposed storage and

transport categories for used SF₆ are given in reference [12].

Pressure vessels according to local pressure vessel acts (for example. TW, ISPEL, ASME, etc.) that are often used in gas carts are in most countries not acceptable for transportation if filled at pressures needed to store sufficient amounts of SF₆. This limits the use of such pressure vessels to local recycling procedures only where transportation is not involved.

9 WORKING WITH SF₆

The following situations may arise when working with SF₆:

- working with new SF₆ : filling ;
- SF₆ filled equipment under normal service conditions: normal leakage ;
- working with used SF₆ which may contain decomposition products: maintenance or extension of switchgear and controlgear ;
- abnormal situations : e.g. internal fault or external fire which may provoke opening of the enclosure :
- during and immediately after the fault: operator safety ;
- after the fault or external fire: restorative work ;
- end of life of equipment: recycling, disposal.

Personnel who are in the vicinity of, or approaching SF₆ filled equipment or undertaking routine maintenance including the testing of SF₆ gas which generally does not require internal access to the SF₆ compartments, do not need any protective clothing or equipment.

When routine or emergency work involves gaining access to SF₆ compartments, unless there is an indication that SF₆ decomposition products are present inside an SF₆ compartment, work may proceed without the need for protective clothing and equipment.

When routine or emergency work involves contact with SF₆ decomposition products protective clothing and equipment is necessary (see appendix A).

Maintenance involving internal access to SF₆ compartments is likely to be infrequent and some MV equipment may be removed from site for this purpose. On high voltage equipment it is generally not practical to remove equipment from site.

9.1 Protective clothing and equipment

Approved types of protective clothing and equipment, as detailed in Appendix A should be available in quantities sufficient for operational and maintenance requirements. It is not intended that every site with SF₆ would be equipped but provision should be made at selected sites, central stores or in mobile units. Operators should be made aware of the nearest source.

After removal of SF₆ gas and any decomposition products from the work area, protective clothing and equipment should be cleaned off using disposable materials and/or an approved vacuum cleaner. It will then be in order to remove protective

clothing and equipment and this may be carried out within the work area, if practicable.

The treatment of disposable items should be carried out as indicated in Section 11. Personnel should wash all exposed parts of the body as soon as possible after leaving the operational area.

Personnel who may be required to make use of the protective clothing and equipment, should be familiar with its method of use as indicated in Appendices B and C of this document and the relevant manufacturer's instructions.

Once cleaning up has taken place, then a respirator may be changed for a face mask for practical reasons.

9.2 Hygiene

When there is any work on equipment which involves contact with SF₆ or its decomposition products, the following conditions must be observed :

- maintain a high standard of personal hygiene ;
- do not eat, drink or smoke ;
- avoid wiping the nose, eyes or face other than with clean paper tissues.

9.3 Procedure for opening SF₆ filled equipment

Prior to opening any equipment containing SF₆, the gas should be removed or evacuated as necessary. Detailed instructions for carrying out the removal of SF₆ gas and subsequent opening and ventilation should be prepared as part of an individual equipment maintenance procedure incorporating the recommendations in accordance with this document.

This procedure will normally include the following [12] :

- identification of any decomposition products ;
- removal of the majority of SF₆ using gas handling plant and storage system ;
- removal of remaining SF₆ ;
- refilling of compartment with air at atmospheric pressure ;
- opening of compartment and removal of adsorbing materials.

9.3.1 Equipment designed for arc interruption

Authorised personnel, or personnel working under the supervision of a suitably authorised person and wearing protective clothing, including overalls, full face mask canister respirator, boots and gloves, may then open the equipment. The approved vacuum cleaner should be used where applicable to remove any decomposition products in the equipment.

9.3.2 Equipment not designed for arc interruption

Unless there is an indication that SF₆ decomposition products are present inside an SF₆ compartment, work may proceed without the need for protective clothing and equipment.

10 ABNORMAL RELEASE OF SF₆

Although very unlikely, abnormal releases of SF₆ can occur for following reasons:

- abnormal leakage ;
- internal fault leading to pressure relief or burn-through of enclosure ;
- external fire causing damage to enclosure.

10.1 Abnormal leakage

Abnormal leakage may be indicated by an SF₆ alarm, where fitted, and an underpressure detector fitted to the equipment.

In the case of a switching compartment, the characteristic odour of decomposition products may be noticed. (The human nose is sensitive and can detect concentrations well below the limit values).

Before work is permitted, it is necessary to ensure that the concentration of SF₆ decomposition products in air are at safe levels. Methods and limits are given in table 1 of reference [12].

10.2 Internal fault

Any persons present at the time of an internal fault should evacuate the area immediately, irrespective whether SF₆ is known or believed to have been released.

Before entering into the area it is necessary to ensure that the concentration of decomposition product remains at a safe level. Methods and limits are given in table 1 of reference [12].

Personnel working under the supervision of a suitably authorised person and wearing protective clothing, and including overalls, full face mask respirator, boots and gloves, may carry out the following :

- Approach the equipment to perform essential operational procedures (if any).
- Approach the equipment after the leakage has stopped to remove any decomposition products, gas remaining in the equipment and gas that may have accumulated in low lying areas. The portable gas extraction equipment with disposable filter, disposable cleaning materials and approved vacuum cleaner shall be used for this purpose. An air blower may be used to disperse accumulations of gas.

If polluted parts of equipment are not treated on site, they should then be wrapped and sealed in polythene, labelled and transported to a suitable location for removal of gas and any decomposition products.

10.3 External fire

SF₆ gas can be released through :

- overpressure in the enclosure ,
- burn-through of organic material.

As SF₆ is non-flammable it cannot feed the fire and indeed could have an extinguishing effect. After release, SF₆ would be rapidly dissipated by convection and should therefore not be exposed to direct heat for long enough for further significant

decomposition to occur. The risk of personal exposure is expected to be extremely low, however the same precautions should be taken before entering the area as for internal fault.

11 TREATMENT OF DISPOSABLE CLOTHING, FILTER AND CLEANING MATERIALS

Before disposal of disposable overalls, cleaning materials, filters and filter materials, they should be treated in the following manner :

- (a). Dissolve 0.5 kg of ordinary washing soda in 45 litres of water in a suitable container such as a dustbin, ensuring that all crystals are completely dissolved.
- (b). Place the materials into the solution.
- (c). Stir thoroughly and leave for 24 hours.
- (d). Pour the bulk of the liquid down the drain and allow running water to flow over the materials in the container for two hours, stirring occasionally.
- (e). After emptying out the water the solid material can be safely disposed of in the normal manner.

Under no circumstances should untreated filter or cleaning material be heated or burnt. The waste water may be run into the foul drain or cesspool in the normal manner, provided it is washed down with at least an equal quantity of water.

Other methods may be also used (cf IEC 61234 [8]).

APPENDIX A : PROTECTIVE CLOTHING AND EQUIPMENT

The following items should be available in quantities sufficient for operational and maintenance requirements.

A1 Respirator

Full face respirator with canister filter for protection against gas and dust complying with the following :

Facepiece	(IEC 61634 [8])
Eye Protection	(IEC 61634 [8])
Canister Filter	(IEC 61634 [8])

A2 Overalls

Disposable pocketless hooded non-permeable coveralls having elastic wrist grips.

A3 Gloves

Lightweight neoprene gauntlet type.

A4 Rubber Boots

Boots as normal issue to staff.

A5 Head Protection

Safety helmets as normal issue to staff.

A6 Eyewash Bottles

Portable unit containing saline solution.

A7 First Aid Equipment

A8 Cleaning Materials

Disposable wiping cloths.

A9 SF₆ Gas handling plant

Includes a portable vacuum pump with a disposable filter.

A10 Vacuum Cleaner

Vacuum cleaner with high efficiency exhaust filter and disposable bag, complying with IEC 61634 [8].

A11 Oxygen Detector

Portable unit with visual and audible warning.

APPENDIX B : RECOMMENDATIONS FOR USE OF RESPIRATOR AND PROTECTIVE CLOTHING

B1 Respirator

Guidance regarding the assembly and fitting of the respirator should be obtained from the manufacturer's instructions supplied with the equipment. It is important to realise that the respirator mask must achieve a good face seal to be effective and this may be prevented by the presence of a beard or facial hair.

The respirator and canister will filter out toxic gas and dust but it is not suitable when the atmosphere is deficient in oxygen. If there is any doubt, then an oxygen deficiency meter must be used to establish if a hazard exists.

The respirator must be worn in addition to the protective clothing when equipment is being opened for maintenance or following an emergency when personnel may come into contact with the gas or associated decomposition products. This also applies to the changing of gas filters on circuit breakers or gas servicing equipment generally.

The respirator canister should be changed after a period of 30 minutes use when the wearer is exposed to SF₆ gas decomposition products, and whenever the respirator is worn by another person. Cleaning of the face mask and breathing tube should be carried out using soap and water, and they may be wiped with a mild solution of disinfectant if required. After use, the canister should be removed and disposed of, but a new one should not be fitted until required, taking care that the shelf life has not expired.

When carrying out maintenance which involves opening the SF₆ filled equipment, all preliminary work which does not require the use of the respirator including removal of the gas and preparation for opening should be completed before the respirator is worn. This will enable the best use to be made of the canister exposure duration, which is 30 minutes.

B2 Protective clothing

The approved disposable overalls have elasticated wrists and ankle fastenings and are fitted with hoods. The overalls are one size and can be worn over the normal overalls.

The disposable overalls, due to the restricted breathing of the material, retain body heat and this should be borne in mind when dressing.

Normal clothing removed should be stored away from contamination in the washing and changing area designated for use during SF₆ working.

The disposable overalls should be worn with the elasticated wrists and ankles over the gloves and boots to prevent any dust entering at these points. The hood should be fitted after the respirator has been donned. A safety helmet can be worn over the hood where necessary.

On completion of work involving use of the protective clothing, including the full face

mask respirator, personnel should clean themselves with disposable cleaning materials before removing the respirator. The overalls should be removed before the boots and gloves and dealt with according to Section 11 of this document, followed by the boots and gloves.

Personnel should wash their hands and face thoroughly before dressing in their normal clothes.

APPENDIX C : SAFETY CHECK LIST

Situations	Risks	Precautions	Body protections
Normal service (without handling gas)	NIL	NIL	NIL
Filling up unused gas	leakage of unused gas	Measure A	NIL
Maintenance operations (with handling used gas)	leakage of used gas	Measure B	- Respirator - Overall - Gloves - Boots - Head protection
Internal fault External fire	heavy leakage of polluted gas	Measure C	- Respirator - Overall - Gloves - Boots - Head protection

Measure A :

efficiently ventilate the room,
do not operate alone.

Measure B :

do not operate alone,
ensure availability of protective clothing and equipment in the vicinity.

If acid odour occurs:

- warn the control engineer,
- ventilate the room,
- and if it is required to enter the room, wear protective clothing and equipment.

Measure C :

warn firemen of the presence of SF₆ ,
warn the control engineer,
ventilate the room,
and if it is required to enter the room, wear protective clothing and equipment.

APPENDIX D : NORMATIVE AND OTHER REFERENCES

The following normative documents contain provisions which, through reference in this text, constitute provisions of this technical report.

- [1] : IEC 60056: 1987, High-voltage alternating-current circuit-breakers
- [2] : IEC 60298: 1990, A.C. metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV
- [3] : IEC 60376: 1971, Specification and acceptance of new sulphur Hexafluoride
- [4] : IEC 60480: 1974, Guide to the checking of sulphur Hexafluoride (SF₆) taken from electrical equipment
- [5] : IEC 60517: 1990, Gas-insulated metal-enclosed switchgear and controlgear for rated voltages of 72, 5 kV and above
- [6] : IEC 60694 : 1980, Common clauses for high voltage switchgear and controlgear standards.
- [7] : IEC 60695-7-1: 1993, Fire hazard testing - Part 7: Guidance on the minimisation of toxic hazard due to fires involving electrotechnical products - Section 1: General
- [8] : IEC 61634 : 1995, Technical Report-High voltage switchgear and controlgear-Use and handling of sulphur Hexafluoride(SF₆) in high voltage switchgear and controlgear.
- [9] : Electra n° 136 June 1991 : Handling of SF₆ and its decomposition products in a gas insulated switchgear, part 1.
- [10] : Electra n° 137 August 1991 : Handling of SF₆ and its decomposition products in a gas insulated switchgear, part 2.
- [11] : Electra n° 164 February 1996 : SF₆ and the global atmosphere.
- [12] : Electra n° 173 August 1997 : SF₆ recycling guide : Re-use of SF₆ in electrical power equipment and final disposal.



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