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National Grid

Technical
Guidance Note

**Guide to SF₆ Handling
Practices**

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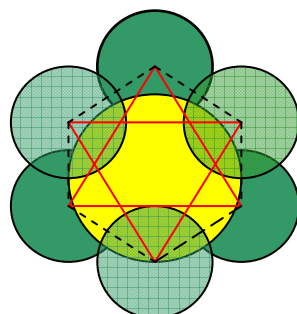
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GUIDE TO SF₆ HANDLING PRACTICES



SF₆ molecule

FOREWORD

Sulphur hexafluoride gas (SF₆) is an essential material used within high voltage electrical equipment because of its dielectric properties that are approximately 2.5 times better than that of air under the same pressure and temperature conditions. The gas is non-flammable, non-corrosive to metals at ambient temperatures and is non-toxic unless decomposed in electrical arcs. When SF₆ gas is subjected to electrical arcs, the gas molecules may be disrupted, but return to their original form. This tendency to repair itself is called "self-healing".

These qualities have made its use desirable within the UK market for over thirty years in circuit breakers, gas-insulated substations (GIS), and related equipment in electrical transmission and distribution systems, and has now progressed to be the main dielectric and insulator for new circuit breakers and gas insulated substations.

SF₆ gas is a powerful greenhouse gas and every effort must be made to minimise both intentional and accidental releases of gas to the environment

1 SCOPE

This Technical Guidance Note (TGN) provides guidance on the monitoring, handling, storage, and disposal of clean and contaminated Sulphur Hexafluoride (SF₆) gas, in accordance with IEC 60376 and IEC 60480, which is used as an insulator and/or interrupting medium within transmission equipment.

The contents of this document targets people who work on a regular basis with SF₆ filled equipment and provides guidance on issues that may be encountered during the normal life cycle of equipment. It also provides personnel with background information, which can be used to gain a better understanding of the events, which could lead to equipment failure.

This document does not deal in depth with the inherent danger from the electrical or pressurised systems associated with SF₆ filled equipment, and assumes the reader to be familiar with appropriate company procedures, safety rules and any associated safety instructions published to manage these dangers.

At the time of writing, this document deals with electrical equipment containing only SF₆ gas in an unmixed state, although it is likely National Grid will utilise SF₆/Nitrogen gas mixtures as an insulating medium within Gas Insulated Lines (GIL's).

2 REFERENCES

IEC 60376:1971	Specification and acceptance of new Sulphur Hexafluoride
IEC 60480:1974	Guide to the checking of Sulphur Hexafluoride taken from electrical equipment.
IEC 60694:1996	Common specifications for high voltage switchgear and control gear standards.
IEC 1634:1995	High voltage switchgear and control gear – Use and handling of sulphur Hexafluoride (SF ₆)
BS 5209:1975	The testing of sulphur Hexafluoride taken from electrical equipment.
BS 349:1973	Identification of the contents of industrial gas containers.
NGTS 1:1999	Ratings and general requirements for plant, equipment, apparatus and services for the national grid system and connection points to it.
NGTS 2.2	Switchgear
NSI 10:Jan1995	Equipment containing Sulphur Hexafluoride (SF ₆)
NS-C2:March 1996	Sulphur Hexafluoride (SF ₆) Filled Equipment.
NS-OH2:Oct 2000	First Aid at Work
Electra Number 173	SF ₆ recycling guide, Re-use of SF ₆ gas in electrical power equipment and final disposal.
Electra Number 137	Handling of SF ₆ and its decomposition products in gas insulated switchgear (GIS).
Epri TR113933	Practical Guide to SF ₆ Handling Practices
HSE EH40	Guidance document on exposure levels.
AA\D4\Z1\AA	Test equipment and specialist tools.
LT/CM/R6/AA	SF ₆ Gas Tests, All Equipment – Routine Maintenance.
TGN(T)77	Simplified Procedure for Dew Point and Relative Humidity Calculations at Normal Working Pressures and Atmospheric Pressure.
WE 1010	Sulphur Hexafluoride (SF ₆) filled equipment.
MB41	SF ₆ Gas usage monitoring
SN-G 106: Jan 2000	The Transport of Dangerous Goods (Safety Advisers) Regulations 1999.
“The Independent”	Global warming special report Friday 15 th December 2000.
LSCP SF6	SF ₆ Release Objectives (Company Intranet document).
Case Study	SF ₆ - Raising Staff Awareness. (Company Intranet document).
Environmental Climate Statutory Instrument (2169)	Consensus among Climate Scientists. (Company Intranet document). Pressure Systems and Safety Regulations 2000

3 DEFINITIONS

3.1 Alarm Pressure

The pressure at which an alarm is generated indicating that “topping-up” is required. For control devices this also corresponds to the Close Lockout pressure. For other switchgear this corresponds to the “Gas Falling” alarm pressure.

3.2 Alarm Density

The density at which an alarm is generated indicating that “topping-up” is required. For control devices this also corresponds to the Close Lockout density. For other switchgear this corresponds to the “Gas Falling” alarm density.

3.3 Emergency First Aider

Someone who has undergone a training course (HSE approval is not required) in administering basic emergency first aid.

3.4 Gas Zone

Discrete pieces of Equipment which may be independently isolated and drained of SF₆. A gas zone may comprise

- a. A single 3-phase enclosure.
- b. A single enclosure of a common item of equipment connected by inter-phase pipework.
- c. Three single-phase enclosures of a common item of equipment connected by inter-phase pipe-work.

3.5 Handling

Any process which might involve contact of workers with SF₆ or SF₆ decomposition products.

3.6 Leakage

Leakage from equipment in service is the unplanned, usually continuous, emission of gas from a sealed or closed system. Leakage does not include releases of gas due to intervention with the systems intended to contain it.

3.7 New SF₆

New or supplier quality SF₆ is SF₆ which complies with the requirements for purity stated in IEC 60376.

3.8 Reclaimed SF₆

SF₆ which complies with the requirements for purity stated in IEC 60480.

3.9 Normal Working Pressure or Rated Filling Pressure

The pressure to which the switchgear is filled before being put into service. It is normally specified by manufacturers at a given ambient temperature.

3.10 Normal Working Density or Rated Filling Density

The density to which the switchgear is filled before being put into service. It is normally specified by manufacturers.

3.11 Purged

A condition of equipment from which any dangerous contents have been removed.

3.12 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.

3.13 Vented

Having an outlet to the atmosphere so that pressure has equalised to atmospheric pressure.

4 EQUIPMENT CLASSIFICATION, CONSTRUCTION AND SF₆ GAS QUALITY.

4.1 Classification

SF₆ gas filled equipment used within an electrical system can be categorised as being either components for switching, such as circuit breakers, disconnectors and earth switches or alternatively for non-switching such as with bus ducting, instrument transformers or cable terminations. The equipment can be either air insulated switchgear, AIS, or gas insulated switchgear, GIS, and sited either in an indoor or outdoor environment.

4.2 Construction

Many factors are considered when purchasing equipment for use on the National Grid system. These include its operational characteristics, maintenance requirements, size, price, delivery, and that it must provide an operational trouble and leakage free service life. These are all important factors to analyse during the tender evaluation process.

All SF₆ equipment has gas pressurised within an enclosure, which is made of metal, porcelain or a composite material and is called a 'gas zone'. The number of gas zones within that equipment will vary depending on the equipment's manufacturing design and function, ranging from one, as seen in a typical AIS gas circuit breaker to multiple GIS gas zone equipment.

Equipment can be *sealed for life*, forming part of the latest generation of low maintenance SF₆ filled equipment, or may be part of a conventional gas zoned system, where its maintenance requirements warrant periodic gas handling. This latter equipment type is that which is used by National Grid.

Although NGTS 2.2 'switchgear' quotes the National Grid requirement of a maximum permitted leakage rate of SF₆ gas from new switchgear to be < 1% per annum as a tender requirement, many manufacturers now supply to National Grid new generation SF₆ gas filled equipment with typical gas leakage rates well below this value.

Pressurised Enclosures:

The SF₆ gas used in electrical equipment is usually pressurised. As the enclosure is under pressure, the normal safety precautions applicable to pressure vessels need to be observed.

In most equipment designs, the enclosures are equipped with one or more of the following:

- a. A pressure relief safety feature.
- b. A pressure/density monitoring device.
- d. Valves for gas handling and sampling the SF₆ gas.
- e. A filter medium which collects moisture and decomposition products.

4.3 Quality Requirements of SF₆ Gas

The National Grid extreme ambient operating temperature range of SF₆ gas filled equipment in accordance with NGTS 1, is from between -25°C and +40°C. Once the equipment's gas zone is filled to the correct gas density, a variation in gas temperature has the effect of altering the equipment's gas zone pressure. Incorrect filling density, particularly when coupled with any impurities present within the gas, may radically affect the electrical performance of the switchgear insulating system.

In order to keep the switchgear manufacturing costs low and the size of the equipment down, high standards of gas quality and equipment gas zone cleanliness are vital for ensuring a reliable and trouble free operational life. All SF₆ equipment used by National Grid employ a closed gas system and provided that the procedures set out in Network Services work specifications, equipment manufacturers maintenance manuals and the advice within this document are adhered to, long term integrity of the equipment can be achieved.



4.4 Relationships between SF₆ Gas Density, Pressure and Temperature

As mentioned within section 4.3 of this document, the electrical performance of SF₆ filled equipment is dependent on the gas density within it. To ensure the equipment's electrical design performance is maintained, switchgear manufacturers *normally* express gas-filling procedures in terms of either a given pressure at a gas temperature of +20°C or density, as required by IEC standards, although some early literature uses a reference temperature of +15°C.

Therefore in order to determine if equipment is adequately filled, it is important to establish the density or pressure and temperature of the gas within the gas zone. Methods of determining the equipment true gas density from pressure are given below:

- a) Measure the SF₆ gas pressure and correct for temperature by:
 - i) Using a temperature compensated gauge that will display the +20 °C equivalent pressure.
 - ii) Using an uncompensated pressure gauge or transducer and use the pressure/temperature/density characteristic given in figure 1a to determine the density or +20 °C equivalent pressure.
- b) Measure gas density directly with the use of a calibrated density transducer.

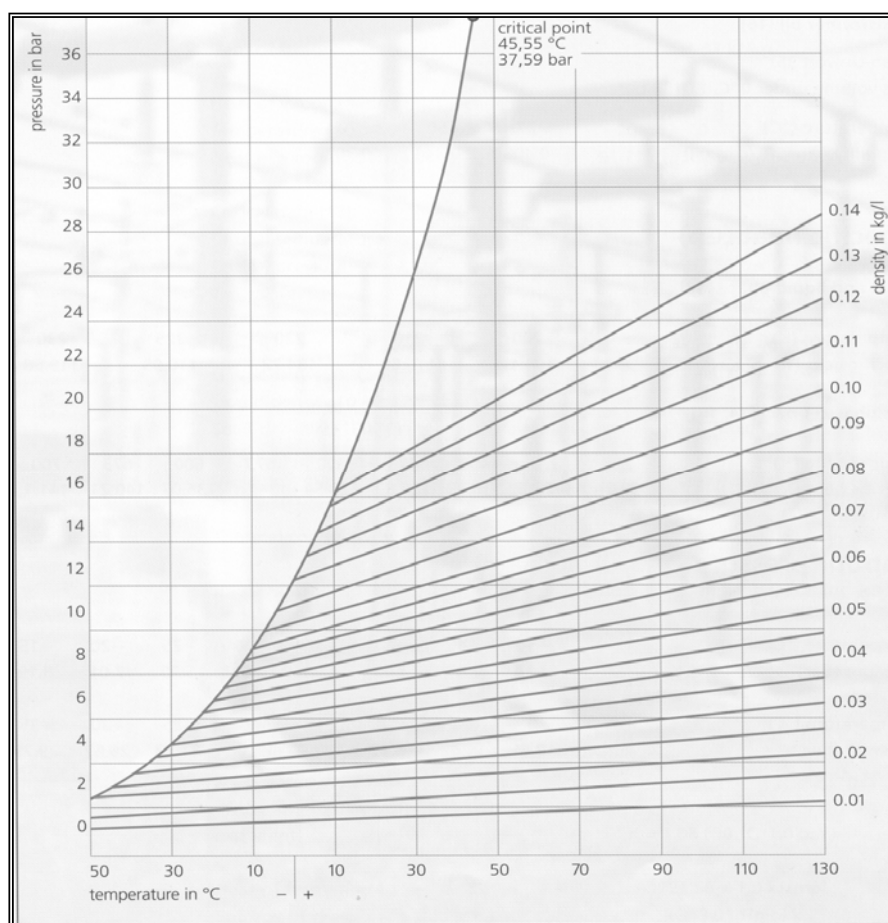


Figure 1a – Relationship between SF₆ Gas pressure, Density and Temperature.

For a given gas pressure within a gas zone the gas density will change in inverse proportion to its temperature, i.e. as gas temperature falls, gas density rises.

As an example, equipment filled to 7.5 bar at 20 °C will have a lower gas density than that equipment filled to 7.5 bar when at 0 °C.

From the values given above we can see that density within the zone actually increases from 50 g/l to 55 g/l for a fall in gas temperature of 20 °C.

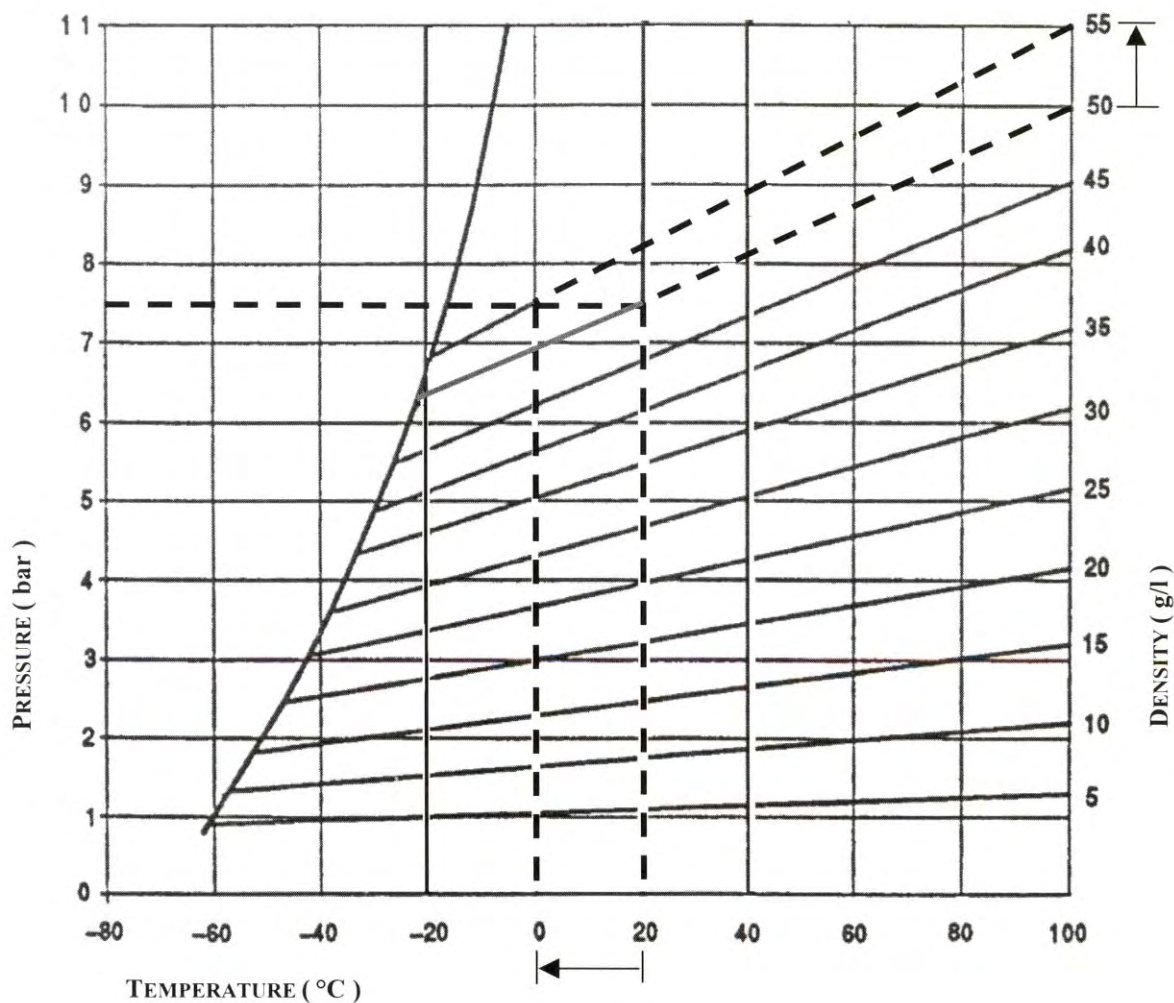


Figure 1b – Gas density changes inversely with temperature for a given pressure

Alternatively, we can say that for a given gas density, gas pressure will change in proportion to its measured temperature. An example of this is equipment filled to a density of 50 g/litre at 20 °C will have a higher gas pressure than if the equipment is filled to a density of 50 g/litre at -20 °C.

From the plot below it shows the equipment pressure falling from approximately 7.5 bar to 6.3 bar over a 40 °C temperature shift.

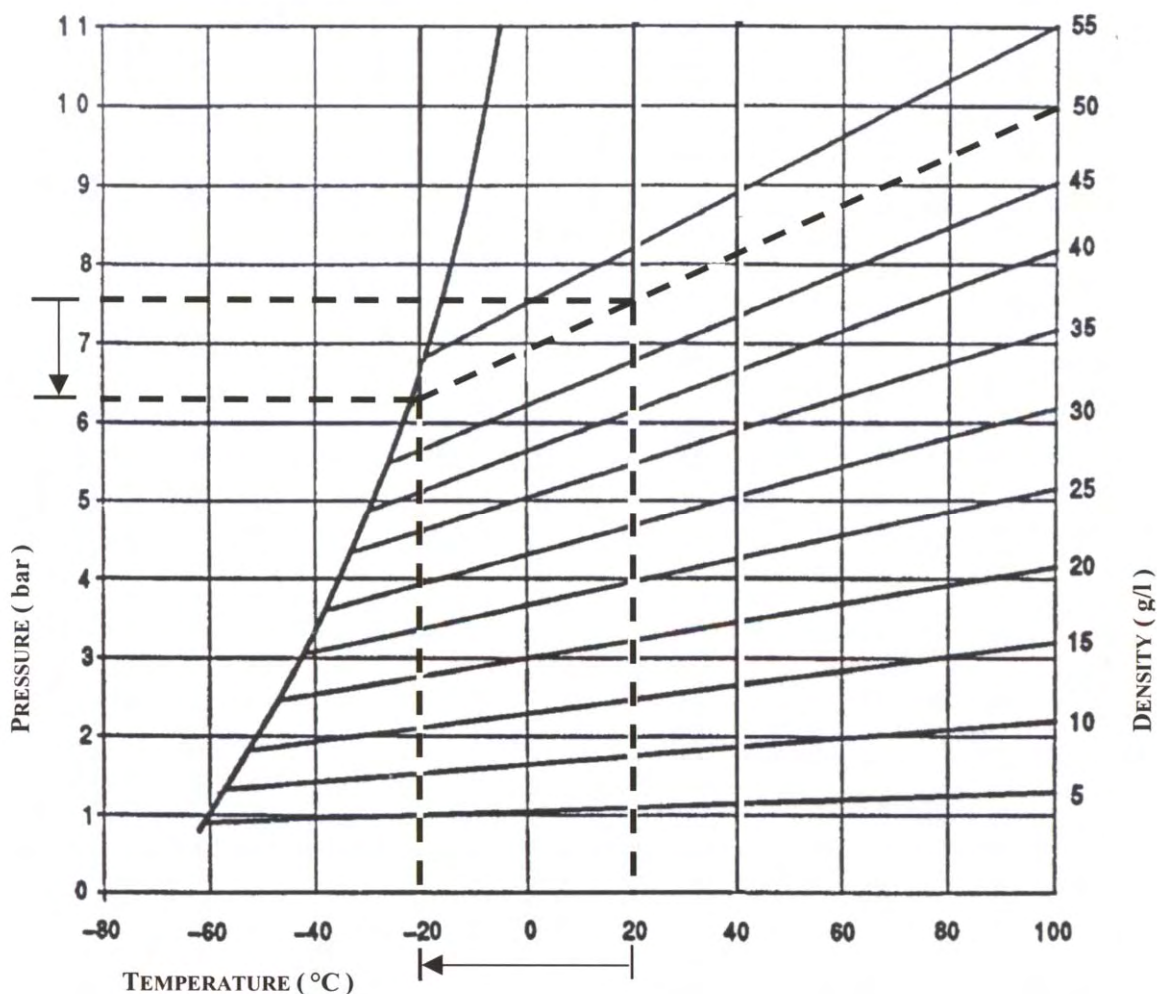


Figure 1c – Gas pressure changes proportionally with temperature for a given density

5 NEW SF₆ GAS: PROPERTIES AND EXPOSURE LIMITS

Sulphur hexafluoride (SF₆) is a very stable and inert gas that does not occur naturally. It is colourless, non-toxic, non-flammable, insoluble in water, does not support life and mixes very slowly with air. Its dielectric strength is about 2.5 times that of air under same pressure and temperature conditions. At normal room temperature and pressure (20°C and 1 Bar), it is gaseous and has a density of 6.06 g/l (approximately 5 times heavier than air), making it one of the heaviest known gases. Since its critical temperature is 45.6°C, it can be liquefied by pressurisation at normal temperatures and is normally transported as a liquid in cylinders, see table 1 for the physical properties of SF₆ gas.

Table 1- Physical properties of pure SF₆ gas

Properties of SF ₆	Value	Units
Density at standard temperature and pressure	0.382	lb/ft ³
	6.06	KG/m ³
Density ratio with air	5.07	-
Molecular weight	146.05	-
Density of liquid at boiling point	73	lb/ft ³
	1168	KG/m ³
Expansion ratio from liquid to gas	225	-
Boiling point at 1 atmosphere	-83	°F
	-64	°C
Critical pressure	547.1	lb/in ² Abs
	3,772	KPascals
Triple point pressure	33.7	lb/in ² Abs
	232	KPascals
Triple point temperature	-58	°F
	-50	°C
Thermal conductivity at 32 °F	0.00813	Btu/ft/hr/°F
at 0 °C	435	Cal/cm-sec-°C

5.1 Exposure limits to SF₆ gas

Exposure tests performed on animals and humans to concentration levels of 80% pure SF₆ / 20% O₂ have produced no adverse medical effects. Due to the remote possibility of contamination of the pure gas by impurities introduced during the gas manufacturing process or from normal in-service conditions, occupational exposure limits (OEL's) with the gas have been assigned in accordance with the HSE guidance note EH40 and are shown below.

- a. Long term exposure limit (LTEL), 8 hour working day, at 1000ppmv.
- b. Short term exposure limit (STEL), 15 minute reference period, at 1250ppmv.

The LTEL limit of 1000ppm may be exceeded, if the oxygen content within the room or confined space is measured and seen to be not less than 19% by volume and that the SF₆ gas is perceived to contain no impurities. Only new gas to IEC 60376:1971 can be perceived as containing no significant impurities.

SF₆ gas that has been introduced into equipment and subjected to normal service conditions must be assumed as having impurities present and so the 1000ppmv LTEL or 1250ppmv STEL limit must be upheld.

6 USED SF₆ GAS- IMPURITIES, ITS ORIGINS AND ALLOWABLE LIMITS

6.1 Impurity Origins

A sample of SF₆ gas taken from electrical equipment may contain several types and amounts of impurity. These impurities can be categorised as originating either from within the manufacturing process and introduced into the gas zone during the gas handling process, or alternatively that the impurities are internally generated within the equipment by the normal or abnormal in-service condition. These impurities that may be found within the equipment's gas zone must be strictly controlled in order that the equipment electrical integrity is maintained. Table 2 below lists the predominant types and their common sources of contaminants found within equipment whilst table 6 gives more information relevant to each expected decomposition bi-product.

Table 2 - Origins and types of impurities found within SF₆ filled equipment

SF ₆ situation	Impurities Sources	Possible impurities
During gas handling	Leaks, contamination and incomplete evacuations	Air, Oil, Moisture, Particulates
Within non-switching equipment	Desorbition	Moisture
	Partial discharges : Corona and Sparking	Moisture, HF, SO ₂ , SOF ₂ , SOF ₄ , SO ₂ F ₂ , SIF ₄ , S ₂ F ₁₀ , SF ₂ , CS ₂
Within switching equipment	Switching arcs and electrical erosion	Moisture, HF, SO ₂ , SOF ₂ , SOF ₄ , SO ₂ F ₂ , CuF ₂ , SF ₄ , WO ₃ , CF ₄ , AlF ₃ , SIF ₄ , S ₂ F ₂ , CS ₂ , SF ₂ , WF ₆
	Mechanical erosion	Metal dusts, particles
Fault Arcing	Melting of materials and SF ₆ decomposition products	Air, Oil, Moisture, HF, SO ₂ , SOF ₂ , SOF ₄ , SO ₂ F ₂ , SF ₄ , CF ₄ .
		Metal dusts, particles, AlF ₃ , FeF ₃ , WO ₃ , CuF ₂

6.2 Predicted Impurity Levels within Used SF₆ Gas.

The amount of impurity found within the gas zone is dependant on a number of factors, each playing their own very important and unique function, and so it is difficult to say exactly how much and of which type of impurity would be found. For example, many compounds would be generated during the decomposition of the SF₆ gas when exposed to an electrical fault arc, but the amounts generated would be as a result of the arc energy and with which internal equipment component the arc was exposed too. Not withstanding this, table 3 below gives the expected degree of SF₆ decomposition products.

Table 3 – Amounts of impurity likely to be present within a gas zone

SF ₆ equipment applications	Expected Impurity amounts
Compartments which contain no active parts, such as busbars and current transformers.	Gas: Low, from zero to a few tenths of a percent. Solids: Little or no visible powder deposits
Compartments which contain active parts such as a circuit breaker.	Gas: Medium, up to a few percent Solids: Light powder deposits, dependent on service operations.
Any enclosure in which abnormal arcing has occurred, but where rupture of the enclosure was prevented.	Gas: High levels should be expected, could exceed 5%. Solids: Medium to heavy powder deposits
Any enclosure in which abnormal arcing has occurred, and where rupture of the enclosure has occurred.	Gas: A mixture of decomposed gas and air. Possible high concentrations of acid would be seen. Solids: Medium to heavy powder deposits, much of which may already have been expelled due to rupture.

6.3 Maximum Acceptable Impurity Levels

Having impurities present within an equipment gas zone may result in a risk of equipment damage. It is therefore extremely important that these impurities are kept to within the declared limits by using correct gas handling, processing and monitoring techniques.

The maximum acceptable impurities levels for new gas, reclaimed gas and from existing gas within switchgear gas enclosure that has been subjected to normal service conditions is outlined within a number of published standards. These are IEC 60376 for new gas and IEC 60480 for reclaimed gas, the most relevant sections of which are combined with other important information and displayed within table 4 below.

Table 4 - SF₆ contaminants, their origins and the maximum tolerable impurity levels allowed in equipment.

Contaminants	Main Origin	Deteriorating effect on	Maximum tolerable impurity levels in equipment See Note 1.	Maximum tolerable impurity levels in equipment after gas handling but prior to commissioning	Impurity levels for reclaimed SF ₆ to be reused in accordance with IEC 60480	Impurity levels for new SF ₆ in accordance with IEC 60376
Air (O ₂ + N ₂) CF ₄	Handling Switching Arcs	Switching, Gas insulation	3% volume total	2.5% volume total equating to 0.5% O ₂	2% volume total	0.05% volume total
Humidity / Water	Desorbition from surfaces and polymers	Surface insulation	<u>8.5 bar -absolute equipment</u> 500ppmv - equating to -27°C dewpoint at 1bar <u>5.5 bar absolute equipment</u> 750ppmv – equating to -23°C dewpoint at 1 bar <u>4.0 bar absolute equipment</u> 1000ppmv - equating to -20°C dewpoint at 1 bar These figures give a - 5°C dewpoint equivalent value at equipment normal operating pressures (absolute) of 8.5 / 5.5 / 4 bar	350ppmv equating to -30°C dewpoint at 1 bar	122ppmv equating to -40°C dewpoint at 1 bar	122ppmv equating to -40°C dewpoint at 1 bar

- 1 bar equates to atmospheric pressure or 100kPa

Contaminants	Main Origin	Deteriorating effect on	Maximum tolerable impurity levels in equipment See Note 1.	Maximum tolerable impurity levels in equipment after gas handling but prior to commissioning	Impurity levels for reclaimed SF ₆ to be reused in accordance with IEC 60480	Impurity levels for new SF ₆ in accordance with IEC 60376
SF ₄ , WF ₆ , SOF ₄ , CS ₂ , SF ₂ , S ₂ F ₂ , S ₂ F ₁₀ , SiF ₄	Arcing, Partial Discharges	Surface insulation	100 ppmv	50 ppmv total acidity 12 ppmv (SO ₂ + SOF ₂)	50 ppmv total acidity 12 ppmv (SO ₂ + SOF ₂)	2.2 ppmv of HF
SOF ₂ , SO ₂ , HF, SO ₂ F ₂ , CF ₄	Secondary reactions	Toxicity	2000 ppmv	25 ppmv HF	25 ppmv for HF	
CuF ₂ , WO ₃ , WO ₂ F ₂ , WOF ₄ , WF ₆ , AlF ₃ FeF ₃	Contact erosion in switchgear Internal Arcs	Toxicity	Non critical	No value	No value	No value
Carbon	Polymer carbonisation	Surface insulation	Low	No value	No value	No value
Metal Dust	Mechanical wear	Gas insulation				
Oil	Pumps and lubrication	Surface insulation	Low	10 ppmv (see note 2)	10 pmv (see note 2)	No value

Table 4 (continued) - SF₆ contaminants, their origins and the maximum tolerable impurity levels allowed in equipment.

- Note 1: The use at these levels increases risk of equipment degradation and plant failure and must only be considered as a short term measure. Plant specific approval is required by Network Engineering Manager in these cases.
- Note 2: If the gas handling equipment (pump, compressor) contains oil, it may be necessary to measure the oil content within the SF₆ gas