The European Association of the Electricity Transmission and Distribution Equipment and Services Industry

T&D EUROPE
Frequently asked Questions (FAQ) and Answers on SF_6

About T&D Europe

T&D Europe is the European Association of the Electricity Transmission & Distribution Equipment and Services Industry, which members are the European National Associations representing the interests of the electricity transmission and distribution equipment manufacturing and derived solutions. The companies represented by T&D Europe account for a production worth over € 25 billion, and employ over 200,000 people in Europe. Further information on T&D Europe can be found here: http://www.tdeurope.eu

Based on the European F-Gas (EU) No. 517/2014 regulation *[2]*.

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1. *Vocabulary:*
   Elaboration of some terms and expressions relevant for the electrical energy sector to better understand this FAQ

1.01	HV (high-voltage) and MV (medium-voltage)	According to international standards like IEC, HV (high-voltage) is any voltage above 1 kV AC. MV (medium-voltage) is not fully defined in IEC. However, it is of common use that MV refers to voltages between 1 kV and 52 kV and that HV refers to voltages above 52 kV up to several hundreds of kVs.
1.02	Electrical transmission network	The term applies to the lines, intended for the bulk transfer of electrical energy from high-voltage generating power plants to HV/MV substations, located near demand centres and considered as part of the transmission network. This part of the whole electrical power grid typically operates at voltages above 52 kV up to several hundreds of kVs.
1.03	Electrical distribution network	The term applies to the lines between the HV/MV substations and consumers of the electrical energy or from/to medium-size generators. The electrical distribution network can be divided into two parts, depending on the operating voltage: • Medium-voltage distribution network, which connects the HV/MV substations with the MV/LV substations. Typically the medium-voltage distribution operates at voltages above 1 kV up to 52 kV. • Low-voltage distribution network, which connects the local MV/LV substation with consumers and prosumers of electrical energy. The operating voltage is up to 1 kV. Typical in Europe is 400 volts.
1.04	T&D equipment	This term stands for electrical equipment used for the transmission and distribution of electrical power by the electrical network.
1.05	Electrical switchgear	In conjunction with the (EU) F-Gas Regulation's No. 517/2014, Art. 2 (36) *[2]* this term stands for switching devices and their combination with associated control, measuring, protective and regulating equipment, and assemblies of such devices and equipment with associated interconnections, accessories, enclosures and supporting structures, intended for usage in connection with the generation, transmission, distribution and conversion of electric energy.
1.06	Closed pressure system	It is a term applied to gas-filled compartments of switchgear, defined in IEC 62271-1 *[1]* as a "*volume which is replenished only when needed by manual connection to an external gas source*". Generally high-voltage switchgear are closed pressure systems.
1.07	Sealed pressure system	It is a term applied to gas-filled compartments of switchgear, defined in IEC 62271-1 *[1]* as a "*volume for which no further gas or vacuum processing is required during its expected operating life*", typically having a leakage rate below 0.1 %. Generally, medium-voltage switchgear are sealed pressure systems.

1.08	Sealed for life system	This term does not appear in IEC standards, but it is very commonly used, considered as equivalent, or popular replacement, to the standardized term "sealed pressure system".
1.09	Hermetically sealed system	This term does not exist in the vocabulary of electrical engineers. The revised F-Gas Regulation extended the definition, initially only made for the cooling and refrigeration sector, also to cover electrical switchgear. Since the tightness requirements for all SF6-filled electrical switchgear, being either a controlled, closed or a sealed pressure system, the term "hermetically sealed system" has no value for the electrical sector.
1.10	Yearly leakage rate	The term is used to quantify the maximum permissible amount of gas loss per year from gas-filled switchgear. It is equivalent to the relative leakage rate defined in IEC 62271-1 *[1]* as "*absolute leakage rate related to the amount of gas in the system at rated filling pressure, expressed in percentage per year*". State-of-the-art electrical switchgear show very low leakage rates: • for closed pressure systems below 0.5 % per year, • for sealed pressure systems below 0.1 % per year.
1.11	Expected operating life	This term is used to indicate the time span of service for which the apparatus is designed. Electrical switchgear are typically designed for a very long expected operating life in the range of 30 years or even exceeding 40 years.
1.12	Medium-voltage secondary switchgear	This term is neither defined in the F-Gas Regulation (EU) No. 517/2014 *[2]* nor in any IEC Standard. However, it is a commonly used term for medium-voltage switchgear used in MV/LV substations of the electrical distribution networks, typically enabling load-break functions.
1.13	Load-break switch	A load-break switch is a mechanical switching device, capable of making, carrying and breaking currents under normal circuit conditions, which may include specified operating overload conditions and also carrying for a specified time currents under specified abnormal circuit conditions (such as those of short-circuit). A load-break switch may have short-circuit making capacity, however it does not have short-circuit breaking capacity.
1.14	Prosumer	A prosumer of electrical power consumes and produces power. The term is derived from "prosumption", a dot-com era business term meaning "production by consumers". In a nutshell, the energy transition is putting an end to the old dichotomy between producers and consumers of electricity. Instead, we now have prosumers who can do both.

2. ***The revised (EU) F-Gas Regulation's No. 517/2014 [2] impact on electrical switchgear. What is unchanged? What has changed?***

No.	***Question***	***Answer***

2.01	What the European F-Gas Regulation (EU) No. 517/2014 *[2]* is about?	In its "Climate Action" program the European Commission targets - among others - to cut EU's greenhouse gas emissions at least by 40 % by 2030 compared with 1990 *[43]*. Under this roof the European Union has adopted a legislative act to control emissions from fluorinated greenhouse gases (F-gases), including Hydro fluorocarbons (HFCs *[3]*). The European F-Gas Regulation (EU) No. 517/2014 *[2]* states under its foreword (2) that "Non-CO2 emissions, including fluorinated greenhouse gases but excluding non-CO2 emissions from agriculture, should be reduced by 72 % to 73 % by 2030 and by 70 % to 78 % by 2050, compared to 1990 levels." The European F-Gas Regulation covers the key applications in which F-gases are used, following two tracks of action: • Improving the prevention of leaks from equipment containing F-gases. Measures comprise the containment of gases and proper recovery of equipment, training and certification of personnel and of companies handling these gases, and labelling of equipment containing F-gases. • Avoiding the use of F-gases where environmentally superior alternatives are cost-effective. Measures include restrictions on the marketing and use of certain products and equipment containing F-gases.
2.02	Why the 2006 F-Gas regulation has been revised?	Art. 10 of the F-Gas regulation (EC) No. 842/2006 stated that a report concerning the experiences of the application of this regulation shall be published in 2011 and appropriate proposals for its revision shall be presented. This procedure resulted in the existing revision the F-Gas Regulation (EU) No. 517/2014 *[2]*.
2.03	Does the F-Gas regulation (EU) No. 517/2014 *[2]* only deal with SF6 in electrical switchgear?	No, the F-Gas regulation is applicable to many fluorinated gases with environmental impact - in total 27 substances (42 substances concerning reporting) - which have wide applications in refrigeration and air-conditioning equipment, heat pumps, fire protection equipment, etc. or used in foams, technical aerosols or as solvents. Concerning SF6 this regulation does not only deal with applications in electrical switchgear, but also with SF6 applied in • windows, footwear and tyres, where it has been banned in Europe • magnesium die-casting, where its use has been restricted in Europe • medical and military equipment
2.04	What are the main topics newly covered by the revised F-Gas Regulation (EU) No. 517/2014 *[2]*?	For electrical switchgear there are a few additional requests concerning leakage checks and leakage detection systems, labelling, reporting and training and certification of personnel handling SF6.
2.05	Does the F-Gas regulation (EU) No. 517/2014 *[2]* include or plan restrictions using of	There is no restriction of application of SF6 in electrical switchgear, which is above all kept in a closed cycle. However, concerning the use of SF6 in new medium-voltage secondary switchgear a report shall be published no later than July

	SF6 for electrical switchgear?	2020, assessing whether cost-effective, technically feasible, energy-efficient, safe and reliable alternatives exist, which make the replacement of fluorinated greenhouse gases possible.
2.06	Can another revision of the F-Gas regulation (EU) No. 517/2014 *[2]* be expected in future?	The F-Gas Regulation (EU) No. 517/2014 *[2]* already states that a comprehensive report on the effects of this Regulation shall be published no later than December 2022. It shall include in particular • a forecast of the continued demand for HFCs *[3]* up to and beyond 2030, • an assessment of the need for further action in light of existing and new international commitments regarding the reduction of fluorinated greenhouse gas emissions, • an overview of Standards, Safety legislation and building codes in relation to the transition to alternative refrigerants, • a review of the availability of technically feasible and cost-effective alternatives to products and equipment containing fluorinated greenhouse gases and not yet covered by the F-Gas Regulation, taking into account energy efficiency.
2.07	Is there any quota of SF6 quantity per year used for electrical switchgear?	There is no quota system for the use of SF6 in electrical switchgear. The F-Gas Regulation (EU) No. 517/2014 *[2]* only defines a quota system for HFCs *[3]*.
2.08	What has to be considered concerning leakage checks for electrical switchgear?	The F-Gas Regulation (EU) No. 517/2014 *[2]* clarifies the cases when periodic leakage checks shall be performed. If the leakage rate is less than 0.1 % per year, or the switchgear containment (individual gas filled compartment) includes less than 6 kg SF6, or the switchgear is equipped with a permanent leakage detection system (manometer, pressure switch or gas density monitor), there is no need for periodic leakage checks. In practical medium- and high-voltage switchgear comply with at least one of these criteria and therefore leakage checks need not be performed *[47]* except in some rare cases.
2.09	Is it mandatory to add a leakage detection system to electrical switchgear?	As soon as a separate switchgear gas compartment contains F-Gas covered by the F-Gas regulation with more than 500 t of CO2-equivalent *[4]* (equals about 21 kg SF6), it is mandatory to equip it with a permanent leakage detection system. The proper function of this leakage detection system must be checked at least every six years.
2.10	Is there a need to specify a leakage rate for electrical switchgear?	Generally there is no need to specify a leakage rate for electrical switchgear, but if the manufacturer's specification states an annual leakage rate less than 0.1 % for the equipment, this information shall be put on the switchgear label.
2.11	What has to be considered for labelling electrical switchgear?	There is no standard format for the label, but instructions for it are given in Article 12 of the F-Gas Regulation (EU) No. 517/2014 *[2]* as well as in the dedicated Implementing Regulation (EU) No. 2015/2068. It shall contain: • the text "contains fluorinated greenhouse gases", • the accepted industry designation for the fluorinated

		greenhouse gases concerned or, if no such designation is available, its chemical name, • the gas quantity expressed in kg and in its CO2-equivalent *[4]* in tonnes, and its GWP *[5]*. The label shall be put adjacent to the service ports for charging or ~~r~~recovering the fluorinated greenhouse gas or on that part of the product/equipment that contains the fluorinated greenhouse gas. Application of the labelling rules shall apply for each new product put on the market in Europe starting January 2017.
2.12	Different values of GWP *[5]* of SF6 are stated in the literature. What shall be chosen for labelling?	The GWP *[5]* of SF6 is periodically checked by the IPCC *[6]*. The value 22,800 was defined in the IPCC Assessment Report no. 4 and is reflected in the F-Gas Regulation (EU) No. 517/2014 *[2]*. It shall be used for labelling, even if a slightly different value (23,500) has been mentioned in the IPCC Assessment Report no. 5.
2.13	Who shall report and what shall be reported on SF6?	F-gas reporting is explained in the Implementing Regulation (EU) No. 1191/2014. According to its Annex Section 3 only exports of bulk gases, including any quantities shipped alongside equipment for the purpose of charging that equipment after export shall be reported. Due to the low threshold fixed under the obligation of reporting, in practice each manufacturer of high-voltage equipment, supplying the charging gas alongside the equipment, will be obliged to annually report. According to the Regulation Annex Section 11 producers of products/equipment manufactured in the European Union shall not report on products/equipment where the contained gases were previously imported into or produced in the European Union. Therefore manufacturers exporting sealed pressure system switchgear (mainly medium-voltage switchgear) are not obliged to report. It is recommended to contact National Authorities for proper procedure.
2.14	How the SF6 reporting is organized?	Reporting shall be delivered to the European Commission annually, by March 31. A template is available in Regulation (EU) No. 1191/2014.
2.15	What are the user's obligations for monitoring and reporting SF6-data of medium-voltage switchgear?	A user monitoring and reporting of SF6 emissions for medium-voltage switchgear is out of the scope of the F-Gas Regulation (EU) No. 517/2014 *[2]*. The National Authorities must develop their own monitoring systems in order to meet their obligations under the Kyoto Protocol *[7]* (refer to Article 20 of the F-Gas Regulation). As far as sealed pressure systems are concerned (typically valid for medium-voltage switchgear), users do not need to monitor or report SF6 emissions. Therefore they only have to assure that the end-of-life disposal is carried out by certified personnel of a qualified entity in accordance with European Regulation (EU) No. 2015/2066.
2.16	Is it necessary to hold a certificate for SF6 handling?	Concerning certificates, the F-Gas regulation (EU) No. 517/2014 *[2]* refers to high-voltage switchgear (which in its context means all voltage levels above 1 kV) and the Implementing Regulation (EU) No. 2015/2066 specifically demands that personnel involved in

		handling SF6 need to hold a certificate when carrying out the following tasks on electrical switchgear: • installation, • servicing, • maintenance, • repair, • decommissioning of SF6 switchgear. Practically, for sealed pressure system medium-voltage switchgear it is only necessary to hold a certificate to recover SF6 at the end of its operating life. Note: Regulation (EC) No. 305/2008 is still valid until June 30, 2017. Starting July 1, 2017, the Implementing Regulation (EU) No. 2015/2066 applies. Holders of certificates issued pursuant to Regulation (EC) No. 305/2008 may renew their certificate without repeating examination.
2.17	Is a certificate for SF6 handling issued in one EU Member State also valid all over EU?	Yes, according to Regulation (EU) No. 2015/2066, a certificate issued in one European Member State is valid in other States of the European Union. However, each State may ask for a translation of the certificate into further languages used in the European Union.
2.18	What are the end-of-life procedures for electrical switchgear?	If electrical switchgear reaches its end of operating life, SF6 has to be recovered by certified personnel of a qualified entity, in accordance with European Regulation (EU) No. 2015/2066. Switchgear manufacturers can provide state-of-the-art information on how to perform this gas recovery safely and environmentally friendly, avoiding any unintended emissions.

3. *Voluntary commitments [8]*

No.	Question	Answer
3.01	What are the main commitments stated in the voluntary actions/agreements of electrical equipment manufacturers and users concerning use of SF6 *[8]*?	Electrical equipment manufacturers, its users, gas manufacturers and entities performing the end-of-life process including SF6 recovery are committed *[8]* to: • avoid and continuously reduce SF6 emissions in manufacturing and during its service time, • reduce the amount of applied SF6 in new electrical equipment, • invest in research and development for viable, comparable alternatives. A clear monitoring and annual reporting of SF6 applications and emissions has been established to prove the progress. For specific details in a given Member State please consult the concerned National Associations.
3.02	How effective the voluntary actions taken by manufacturers have been?	The production processes of medium-voltage and high-voltage switchgear in Western Europe have been improved to reduce the specific SF6 emission rates down to one third from 1995 to 2003. This has been proven by a study of Energy and Climate Consultancy Ecofys *[9]*, dated 2005. Since 2003 further continuous improvement

		has been reached resulting in additional emission reductions and state-of-the art high tech SF6 equipment made in Europe. Each manufacturer of SF6 containing electrical equipment annually reports data of purchased SF6, retrieved SF6, returned SF6 and applied SF6 in electrical equipment. The emissions are summarized by a National Third Party and targets for further actions are established based on the results.
3.03	Are voluntary agreements *[8]* still necessary today?	Voluntary agreements *[8]* were created before any F-Gas Regulation existed. Their advantage is to clearly illustrate the long-term trend in SF6 emission reduction. It is still a good tool to review the best practices and highlight the efforts and progress of the electricity sector. In fact an up-dated study by Ecofys *[9]* published in the year 2010 stated: "*The success of voluntary agreements shows that this could be one flexible and efficient tool beside future regulations to achieve environmental improvements on a global scale. Through these voluntary agreements, the electrical industry proactively contributes to global emission reductions. As a consequence, SF6 emissions will continue to remain very low in the future*"**.**

4. <u>General information on SF6</u>

No.	Question	Answer
4.01	What is SF6?	Sulphurhexafluoride (SF6) is a colourless, odourless, chemically neutral, and inert gas (a substance that is not chemically reactive), non-flammable and 5 times heavier than air. It is not toxic and not ozone depleting. More detailed information is given in IEC 60376 *[10]* and IEC 62271-4 *[18]* or by SF6 gas manufacturers.
4.02	Why SF6 is ideal for high- and medium-voltage switchgear applications?	SF6 is an extremely stable gas with unique physical and chemical properties that make it ideally suited for use equipment for electrical transmission and distribution systems. SF6 is used as insulation and arc quenching medium in high and medium-voltage switchgear.
4.03	Are there other users of SF6 than the electrical switchgear industry?	According to The RAND Corporation *[11]* the electric power industry applies more than 50 % of all SF6 produced worldwide *[31], [33]*. Other significant users are *[12]*: • the metal die casting industry, and • the electronic industry. SF6 is also used particularly for/within: • superconducting particle accelerators, • electron microscopes, • X-ray equipment, and • leakage testing of fuel tanks, pipework systems and packing for radioactive materials.

		It is also known that SF6 is used in several military applications. These quantities are not reported or well evaluated due to its sensitive nature.
4.04	What about ageing process of SF6 gas?	Under equipment's normal operating conditions an aging process of SF6 is not a matter of concern. Due to SF6's unique characteristics and its exceptional stability, no significant or disruptive degradation occurs. If switches or circuit-breakers use SF6 for extinguishing the switching arc during its operation, SF6 might be partly decomposed by the electrical arc followed by a very high degree of gas re-combination afterwards. Nevertheless, even in high-voltage applications this is not an issue from an ageing point of view, since there by-products are absorbed by molecular filters, designed to last over the expected switchgear lifetime.

5. *Application of SF6 in electrical equipment*

No.	Question	Answer
5.01	Is there any SF6 ban for electrical switchgear implemented in any country?	There is no legal SF6 ban implemented in any country worldwide for electrical switchgear. Very few countries have a tax system on certain conditions, e.g. in Europe: Denmark (since 2001, excluding medium-voltage equipment <= 36kV) *[42]*, Spain for SF6 in bottles which might be used for refilling purposes *[39]*.
5.02	Is there any other regulation in place in any country that indirectly restricts use of SF6 for electrical switchgear?	No, there is no regulation implemented in any country worldwide for electrical switchgear that even indirectly restricts use of SF6 in this application. It has to be noted that Australia instituted a carbon tax on July 1, 2012, which also imposed climate-equivalent fees based on CO2 equivalents and thus covered – among many other substances – also SF6. The Australian carbon tax was already repealed two years later, on July 17, 2014 *[46]*.
5.03	Is use of SF6 in electrical switchgear restricted or prohibited by any European Regulation?	Although SF6 - among other greenhouse gases (total 27) - is covered by the European F-Gas Regulation (EU) No. 517/2014 *[2]* there is no restriction or prohibition of its use in electrical switchgear.
5.04	What are the different applications in electrical power equipment using SF6?	Gas-insulated switchgear for high- and medium-voltage (GIS), circuit-breakers (CBs), load-break switches (LBS), power transformers, voltage transformers (VTs), current transformers (CTs), assemblies of high-voltage devices and gas-insulated lines (GIL), capacitors, bushings, etc.
5.05	What are the benefits of high- and medium-voltage SF6 switchgear?	SF6 gas-insulated switchgear show significant number of benefits: • small space requirement, • very high operational reliability, • long operating life,

		• local operator safety, • widely insensitive to harsh environmental conditions, • minimal maintenance expenditure thanks to maintenance-free, gas-tight enclosures (medium-voltage sealed pressure system are even sealed for life), • For SF6 gas-insulated medium-voltage switchgear its low environmental impact and high sustainability has been evaluated using a life cycle assessment *[32]*.
5.06	What is the difference in applying SF6 gas for high-voltage (HV) and medium-voltage (MV) equipment?	Basically there is no difference, both, medium-voltage and high-voltage equipment, use SF6 in gas-tight compartments with negligible leakage rates. In general medium-voltage gas-insulated switchgear operates with SF6 gas pressures slightly above the atmospheric pressure in sealed pressure systems. Low pressure and small sized gas-filled compartments result in small gas quantities, from a fraction of a kg to a few kg. The switchgear's leakage rate during service is extremely low, stated to be max. 0.1 % per year. However real leakage rates of state-of-the-art medium-voltage switchgear are well below that value. Modern high-voltage switchgear typically use closed pressure systems with leakage rates during service less than 0.5 % acc. the maximum permitted value by the respective IEC standards. The range of operating pressures of different high-voltage equipment is fairly broad, but as an average value about five times the pressure used for medium-voltage switchgear is an allowable approximation. Due to the equipment's size and applied gas pressure, the SF6 quantities in high-voltage applications are much higher than for medium-voltage. Typical quantities, depending on type of equipment for high- and medium-voltage (gas-insulated switchgear (GIS), circuit-breakers (CBs), gas-insulated lines (GIL), gas-insulated busducts (GIBs), etc.), vary between a few kg and 1 tonne of SF6.
5.07	When was the first successful application of SF6 in electrical power equipment?	In 1964 fundamental studies started in research and development of SF6 GIS-Technology. SF6 is applied in high-voltage switchgear and equipment since the 1960ies, at first in air-insulated high-voltage equipment (SF6 circuit-breakers). Since the beginning of the 1980ies SF6 is also applied in medium-voltage switchgear. Due to the excellent electrical and chemical characteristics of SF6 new technical achievements could be reached resulting in today's state-of-the-art gas-insulated switchgear (e.g. high reliability over an expected long life-time up to and over 50 years, compact and modular design for space saving electrical power equipment, high switching performance).
5.08	Is replenishment of SF6 needed during equipment's operating life?	Medium-voltage switchgear typically are sealed pressure systems not intending or requiring any replenishment throughout its full operating life. High-voltage equipment, which typically is designed as closed pressure systems, requires gas surveillance during its operating life acc. the manufacturer's instruction. An alarm will be triggered as soon as the gas pressure is below a defined threshold level, requiring investigation of its root cause and replenishment to the

		corresponding operating pressure level.
5.09	How much SF6 gas my equipment contains?	This information can normally be found on the equipment's nameplate. For older equipment please contact the equipment manufacturer.

6. Toxicity

No.	Question	Answer
6.01	Is pure SF6 a health hazard?	Pure SF6 is physiologically completely harmless for humans and animals; it is even used in medical diagnostic and optical surgery. Due to its weight it might displace the oxygen in the air if large quantities are concentrating in underground and/or non-ventilated places. Legislation for chemicals does not categorise SF6 as a hazardous material.
6.02	How high is the Maximum allowable working environment concentration (MAC) *[13]* for pure SF6 in a working environment?	The maximum concentration of SF6 in the working environment shall be kept lower than 1,000 ml/m^3 eq. 6,100 mg/m^3 *[14]*. This value is accepted for a full-time (8 hours a day, 5 days per week) work schedule. It is not related to toxicity, but an established limit for all non-toxic gases which are not normally present in the atmosphere. Therefore, this limit does not mean that higher SF6 concentrations pose any toxic hazard. IEC 60480 *[15]* states: "*In principle, a mixture of 20 % of oxygen and 80 % SF6 can be inhaled without adverse effect.*" In practice the only real risk is suffocation due to the displacement of the oxygen by an accidental abnormal SF6 emission in rooms with deficient ventilation. The normal concentration of oxygen in the atmosphere is about 21 % and a concentration of 19.5 % oxygen is considered being the minimum acceptable oxygen concentration for a healthy working environment. Therefore the presence of up to 7 % (70,000 ppm) of SF6 in the air is considered being not critical but SF6 concentrations above this value are increasingly dangerous and a presence of 20 % SF6 in the air (equals displacement of about 4 % of air's oxygen) will lead to serious risk of suffocation.
6.03	What decomposition products are created in case a SF6-filled equipment encounters an arc fault?	The very high energy of an accidental arc fault will generate gaseous and dusty by-products. Refer to IEC 60480 *[15]* and/or the CIGRÉ *[16]* Report Electra 1991 *[17]* ("*Handling of SF6 and its decomposition products in GIS*", table 2 "*Rough characterisation of the major decomposition products resulting from different sources*") and IEC 62271-4 *[18]*. The decomposition products depend on the type of equipment and its service history. By-product quantities depend on arc fault energy (voltage, current, time) and the type of the SF6-filled equipment. There are various literatures available concerning SF6 decomposition by-products. As an example the US Environmental Protection Agency comments on the most frequent by-products created in SF6 high-voltage circuit-breakers following an arc fault

		[29]. Other by-products can appear depending of type of materials used in the equipment. In case of an accidental arc fault, evacuation of the installation room is always compulsory irrespective or whether the switchgear contains SF6 or not due to possible toxic characteristics of other burned materials.
6.04	How hazardous is used SF6?	Refer to IEC 62271-4 *[18]*, Annex H: "*Procedure for evaluating the potential effects on health of SF6 by-products*". In this Annex a calculation method is given to evaluate the amount of by-products with toxic characteristics generated under different conditions. Using this, it is possible to evaluate potential toxic hazard, taking into account the volume of the switchgear room. Only three gaseous by-products have been identified with significant health hazard, taking into account reaction quantities and its toxicity: SOF2, SO2 and HF (refer to CIGRÉ 1991 report *[17]*). SF6 manufacturer's safety data sheets are available for the public for used SF6 where – among others – working environment concentrations of possible by-products are listed (e.g. Solvay document *[38]*). Reference can also be made to US EPA report, dated January 2002 "*By-products of SF6, Use in the electric power industry*" *[29]*. Calculations show that in practice only in case of an accidental arc fault with massive emission of heavily arced gas a real hazard is created. After such an event evacuation and ventilation is compulsory. This will be necessary for any kind of switchgear due to fumes and vapours with possible toxic characteristics, exposed from burned material like metal, plastic, paints, etc.
6.05	What measures shall be taken if personnel came in contact with decomposed SF6 by-products?	Refer to IEC 62271-4 *[18]*, Annex B: "*Safety and first aid*". Only trained and qualified personnel should handle SF6 and hence be aware of the necessary precautions, protective equipment and actions.
6.06	How used SF6-gas is treated or disposed?	Normally the majority of used SF6 is collected and re-used after proper filtering to reclaim its proper technical grade characteristics. In some special cases disposal of the gas is performed by gas manufacturers who apply high-temperature plasma burning processes to crack and destroy the stable SF6 molecule and its decomposition by-products.

7. *Environment*

No.	Question	Answer
7.01	Is SF6 regulated by the Kyoto Protocol *[7]*?	Yes, the Kyoto Protocol *[7]* under the United Nations Framework Convention on Climate Change (UNFCCC *[26]*) came into force February 16, 2005, and regulates emissions of gases especially

		assumed contributing to global warming (so-called greenhouse gases). These are: • Carbon dioxide, • Methane, • Nitrous oxide, • Hydro fluorocarbons (HFCs *[3]*), • Per fluorocarbons (PFCs) *[19]*, and • Sulphur hexafluoride (SF6).
7.02	Is SF6 regulated by the Montreal Protocol *[20]*?	No, the Montreal Protocol *[20]* considered ozone depleting substances only and therefore does not consider SF6. During its eighth revision (Kigali Amendment, October 2016 *[45]*), HFCs *[3]* – non-ozone depleting substances - commonly used for refrigeration, have now been added.
7.03	Is SF6 harmful for the environment?	SF6 has no ecotoxic *[21]* potential and it does not deplete ozone. Due to its high global warming potential of 22,800 it will contribute to the man-made greenhouse-effect if it is released into the atmosphere. However in state-of-the-art electrical switchgear SF6 gas is applied in gas-tight compartments, effectively minimising leakages and the SF6 is prescribed to be held in a closed cycle during the equipments operating life including decommissioning. This results in a negligible contribution to the global greenhouse effect from electrical equipment. Note: The F-Gas Regulation (EU) No. 517/2014 *[2]*, Article 3 (1) clearly states that "*the intentional release of (any) fluorinated greenhouse gases into the atmosphere shall be prohibited where the release is not technically necessary for the intended use*".
7.04	What is the electrical equipment's contribution to the global emission of SF6 to the atmosphere and the related global warming?	Application of SF6 in electrical equipment does not automatically result in SF6 emissions. Ideally, none of the applied gas shall be emitted into the atmosphere. In reality, minor SF6 emissions occur during the electrical equipment's life cycle (production, installation, operating life, maintenance, unexpected service conditions, end-of-life decommissioning), especially when gas handling is required. Worldwide contribution of electrical equipment with applied SF6 to the global warming is less than 0.1 % (refer to CAPIEL *[22]*, ESA *[23]* and CIGRÉ *[16][24]* and Journal "Carbon Management" *[41]*). In Europe, during 2012-2015 the total SF6 emissions of all applications contributed to approx. 0.15 % of the greenhouse gas emissions, expressed in CO2 equivalent *[36]*. Concerning electrical equipment, an Ecofys study, published 2005 *[25]*, estimates its European contribution to the global warming as 0.05 %. The Journal "Carbon Management", published 2014 *[41]*, states that a fraction of 15% of worldwide SF6 emissions sources - which contribute to the global warming - is related to electrical equipment which equal to approx. 0.02 % contribution.
7.05	Is SF6 a main	SF6 is a minor contributor to the global warming (also refer to

	contributor to global warming?	IPCC *[40]*, NOAA *[44]*). The yearly measured SF_6 emissions to the atmosphere are around 6,000 tonnes *[34]*. Ecofys *[9]* evaluated the annual emissions from electrical switchgear between 1,000 t to 3,000 t by the year 2030, depending on the used scenario *[35]*. SF6 emissions from any kind of activity in the countries listed in Annex I of UNFCCC *[26]* contributed a 0.14 % in CO2-equivalent *[4]* to the total greenhouse gases emitted in 2012 from the same countries. Even if the annual SF6 emissions would increase up to 10,000 tonnes per year, the contribution of SF6 to the global warming will most likely be below 0.3 % in 2020.

8. *Standards and public available documents that deal with SF6*

No.	Question	Answer
8.01	Where information concerning proper handling of SF6 during the entire operating life of an electrical equipment can be found?	SF6 Handling processes are described in international and national standards and recommendations such as: • CIGRÉ *[16]* Brochure 276 *[27]* "*Guide for the preparation of customized practical SF6 handling instructions*", • for electrical equipment manufacturing: Manufacturer's internal instructions, design- and routine-test principles, • IEC 62271-4 *[18]* "*Handling procedures for sulphur hexafluoride (SF6) and its mixtures*". Additional information is given during training procedures for personnel intending to be certified handling SF6.
8.02	Where information concerning quality grades of SF6 to be applied in electrical equipment can be found?	The following international standards deal with quality grade of SF6: • IEC 60376 *[10]* "*Specification of technical grade sulphur hexafluoride (SF6) for use in electrical equipment*", • IEC 60480 *[15]* "*Guidelines for the checking and treatment of sulphur hexafluoride (SF6) taken from electrical equipment and specification for its re-use*".
8.03	Where information concerning proper end-of-life treatment of SF6-switchgear can be found?	The following internationally acknowledged documents are available supplying information concerning end-of-life treatment for SF6 containing electrical equipment: • CIGRÉ *[16]* Brochure 234 *[28]* "*SF6 recycling guide*", • IEC 62271-4 *[18]* "*Handling procedures for sulphur hexafluoride (SF6) and its mixtures*". Additional information is given during training procedures for personnel intending to be certified handling SF6.
8.04	How a user can ensure proper SF6 quality during electrical equipment's operating life?	Sealed for life medium-voltage equipment (sealed pressure system) does not require any SF6 quality checks. It is designed to ensure proper function during its entire operating life (as long as the equipment is operated within its specified operating limits). For other, especially high-voltage equipment, IEC 60480 *[15]* describes different methods of gas analysis applicable for closed pressure systems (on-site analysis and analysis in a laboratory).

8.05	Does a (passive or active) ventilation system have to be installed in the switchgear room or its cables basement?	Buildings containing SF6-filled indoor equipment should be provided with ventilation. Natural ventilation normally is considered to be adequate to prevent the accumulation of SF6 released due to leakages (refer to IEC 62271-4 *[18]*, Annex B "Safety and first aid".
8.06	How used SF6 is to be transported and shipped?	Concerning SF6 shipping, refer to IEC 60480 *[15]*, Chapter "*Storage and transportation of used SF6*".

[1] IEC 62271-1 High-voltage switchgear and controlgear - Common specifications.

[2] REGULATION (EU) No. 517/2014 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006, http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R0517&from=DE.

[3] Hydrofluorocarbon (HFC) is an organic compound that contains fluorine and hydrogen atoms. HFCs are the most common type of organofluorine compounds, especially also used in air conditioning and as refrigerants. They contribute to global warming.

[4] CO2-equivalent means a quantity of a greenhouse gas expressed as the product of the weight of the greenhouse gas and of its global warming potential in relation to CO2 GWP = 1. It is commonly abbreviated by "CO2e".

[5] Global warming potential (GWP) means the climatic warming potential of a greenhouse gas relative to that of CO2, calculated in terms of the 100-year warming potential of 1 kg of a greenhouse gas relative to 1 kg CO2.

[6] The Intergovernmental Panel on Climate Change (IPCC) is the International body for assessing the science related to climate change. The IPCC was set up in 1988 by the World Meteorological Organization (WMO) and United Nations Environment Program (UNEP) to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation. Web page: www.ipcc.ch.

[7] The Kyoto Protocol is an international treaty which extends the 1992 United Nations Framework Convention on Climate Change (UNFCCC) that commits State Parties to reduce greenhouse gas emissions, based on the premise that a global warming exists and that human-made CO2 emissions have caused it. The Kyoto Protocol was adopted in Kyoto, Japan, December 11, 1997 and entered into force February 16, 2005.

[8] E.g. in Germany: Solvay, VIK, VDN, ZVEI: „Selbstverpflichtung der SF6-Produzenten, Hersteller und Betreiber von elektrischen Betriebsmitteln > 1kV zur elektrischen Energieübertragung und -verteilung in der Bundesrepublik Deutschland zu SF6 als Isolier- und Löschgas", Mai 2005, www.sf6-energietechnik.de.

[9] Ecofys is a leading international energy and climate consultancy with its headquarter in The Netherlands. Other international offices are located in Belgium, Germany and The United Kingdom. Web page: www.ecofys.com

[10] IEC 60376 Specification of technical grade sulphur hexafluoride (SF6) for use in electrical equipment.

[11] The RAND Corporation is a research organization that develops solutions to public policy challenges to help make communities throughout the world safer and more secure, healthier and more prosperous. Web page: www.rand.org.

[12] Refer to Destatis report "Erhebung bestimmter klimawirksamer Stoffe "Schwefelhexafluorid" (SF6) und "Stickstofftrifluorid" (NF3) ", 2015, published by the German Federal Statistical Office, June 2016, article number 5332401-15700-4, page 6.

[13] Maximum allowable working environment concentration (MAC) is a term of art used in occupational health and safety for the highest concentration of a chemical or potential toxin allowed by law to which a worker may be exposed during an 8-hour period of time.

[14] Refer to publication from Deutsche Forschungsgemeinschaft, MAK- und BAT-Werte-Liste 2012, ISBN: 978-3-527-33427-8. Also refer to TRGS 900, Technische Regeln für Gefahrstoffe, ISBN: 3923221266, 9783923221264. Deutsche Forschungsgemeinschafts web page: www.dfg.de.

[15] IEC 60480 Guidelines for the checking and treatment of sulphur hexafluoride (SF6) taken from electrical equipment and specification for its re-use. IEC web page: www.iec.ch.

[16] Founded in 1921, CIGRÉ, the Council on Large Electric Systems, is an international non-profit Association for promoting collaboration with experts from all around the world by sharing knowledge and joining forces to improve electric power systems of today and tomorrow. Web page: www.cigre.org.

[17] Handling of SF6 and its decomposition products in gas insulated switchgear (GIS), CIGRÉ Working Group 23-03, ELECTRA No. 136, June 1991, p. 69.

[18] IEC 62271-4 Handling procedures for sulphur hexafluoride (SF6) and its mixtures, Ed. 1.0, 2013-08.

[19] Perfluorocarbons (PFCs), are organofluorine compounds with the formula CxFy, i.e. they contain carbon and fluorine. They are useful fluoropolymers, refrigerants, solvents, and anaesthetics.

[20] The Montreal Protocol on substances that deplete the ozone layer (a protocol to the Vienna Convention for the protection of the ozone layer) is an international treaty designed to protect the ozone layer by phasing out the production of numerous substances that are responsible for ozone depletion. It was agreed August 26, 1987, and entered into force on August 26, 1989. Since then, it has undergone eight revisions, the latest in Kigali (adopted, but not in force).

[21] The term "ecotoxic" refers to the potential for biological, chemical or physical stressors to affect ecosystems. Such stressors might occur in the natural environment at densities, concentrations or levels high enough to disrupt the natural biochemistry, physiology, behaviour and interactions of the living organisms that comprise the ecosystem.

[22] The European Coordinating Committee of Manufacturers of Electrical Switchgear and Controlgear (CAPIEL) is the Coordinating Committee for the Associations of Manufacturers of Switchgear and Controlgear equipments for industrial, commercial and similar use in the European Union. Web page: www.capiel.eu.

[23] Environmental Sustainability Approach (ESA) is available from the CAPIEL's National member associations and manufacturers. Refer to CAPIEL web page: www.capiel.eu.

[24] SF6 in the Electric Industry, Status 2000, (CIGRÉ Study Committee No. 23) P. O'Connel et al, ELECTRA No. 200, February 2002, pp 16-25.

[25] Ecofys *[9]*, Sina Wartmann, Dr. Jochen Harnisch, June 2005, "Reductions of SF6 Emissions from High- and Medium- Voltage Equipment in Europe".

[26] Refer to United Nations Framework Convention on Climate Change (UNFCCC). Web page: www.unfccc.int

[27] CIGRÉ-report 276, 2005: Guide for the preparation of customized "Practical SF6 Handling Instructions". A short version appears in August 2005 in ELECTRA.

[28] CIGRE-report 234, 2003: SF6 recycling guide.

[29] By-products of Sulfur Hexafluoride (SF6), Use in the Electric Power Industry, prepared for U.S. Environmental Protection Agency, prepared by ICF Consulting, January 2002, https://www.epa.gov/sites/production/files/2016-02/documents/sf6_byproducts.pdf

[30] Dervos, C.T., and P. Vassiliou. 2000. Sulfur hexafluoride (SF6): Global environmental effects and toxic byproduct formation. J. Air and Waste Manage. Assoc. 50:137-141.

[31] Refer to RAND [11] Project Memorandum 2004-2006 SF6 Data Summary, PM-2327-NEMA, June 2007, Debra Knopman, Katie Smythe.
Refer to www.epa.gov/sites/production/files/2016-02/documents/04-06_data_summary.pdf.

[32] Life cycle assessment SF6 GIS-Technology for Power Distribution – Medium-Voltage –, Summary, Dr.-Ing. Ivo Mersiowsky, Solvay Management Support — Life Cycle & Sustainability —, Hannover, November 2003, p. 10.

[33] Global SF6 Sales 2016 Market Research Report, QY Research Chemical and Material Research Center, November 2016, Table and Figures to §2.4, Global SF6 Volume by Application 2011-2016.

[34] Rigby, M. et al. 2010 History of atmospheric SF6 from 1973 to 2008. Atmos. Chem. Phys. 10 305–10 320.

[35] Ecofys *[9]*, Update on global SF6 emissions trends from electrical equipment –Edition 1.1, Ecofys Emission Scenario Initiative on Sulphur Hexafluoride for Electric Industry (ESI-SF6), Jan-Martin Rhiemeier, Sina Wartmann, Marcello Pagnotta, Natalia Makowska, Xingyu Li, Cologne, July 1, 2010.

[36] United Nations – Framework Convention on Climate Change: Total GHG emissions including LULUCF/LUCF - Classification: Total for category - Type of value: Net emissions/removals - Gas: Various - Unit: GHG CO_2 equivalent.
http://di.unfccc.int/global_map/

[37] ZVEI/FNN "SF6-Daten 2013/2014 für die Energieübertragung und -verteilung >1 kV", 17.06.2014.

[38] Refer to Solvay document number P600000020138, dated Oct 21, 2015

[39] Boletín official del Estado, Núm. 260, Miércoles 30 de octubre de 2013 Sec. I. Pág. 87528. Law 16/2013 of October 29, 2013 "por la que se establecen determinadas medidas en materia de fiscalidad medioambiental y se adoptan otras medidas tributarias y financieras". Especially refer to pages 20-21.

[40] Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang, 2013: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Refer to table 8.2.
http://www.ipcc.ch/report/ar5/wg1/

[41] Journal Carbon Management, 6:3-4, 77-87 (2015): "Reducing SF6 emissions from electrical switchgear", Edgar Dullni, Thor Endre, Yannick Kieffel & Renzo Coccioni, October 1, 2015. ISSN: 1758-3004 (Print) 1758-3012 (Online).
Journal homepage: http://www.tandfonline.com/loi/tcmt20
Link to the article: http://dx.doi.org/10.1080/17583004.2015.1090056

[42] Danish tax Authorities: Skatteministeriet, STV nr 20061 af 01/01/2006 "Punktafgiftsvejledning 2006, del G Miljøafgifter". https://www.retsinformation.dk/

[43] COM (2011) 112, dated March 3, 2011: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, A Roadmap for moving to a competitive low carbon economy in 2050. Refer to paragraph 6.

[44] National Oceanic & Atmospheric Administration(NOAA), NOAA Research, Earth System Research Laboratory – Global Monitoring Division, Halocarbons and other Atmospheric Trace Gases.
https://www.esrl.noaa.gov/gmd/

[45] Also refer to Ozone Action, UN Environment (UNEP), Economy Division: "OzonAction Fact Sheet, The Kigali Amendment to the Montreal Protocol: HFC Phase-Down".
http://www.unep.fr/ozonaction/information/mmcfiles/7809-e-Factsheet_Kigali_Amendment_to_MP.pdf

[46] Also refer to information from Carbon Tax Center (CTC): "Where Carbon Is Taxed".
https://www.carbontax.org/where-carbon-is-taxed/

[47] Refer to publication "Erläuterungen zur neuen F-Gase-Verordnung (EU) 517/2014 bezüglich des Einsatzes von SF6 in der Energietechnik", dated October 2015 by ZVEI - German Electrical and Electronic Manufacturers' Association, Power Engineering Division, Berlin